BBC

HOW WILD IS YOUR CAT?

Your feline friend is more lion than you think *p47*

ASIA EDITION

Knowledge

Vol. 7 Issue 1

SCIENCE • HISTORY • NATURE • FOR THE CURIOUS MIND

INCORPORATING PPC SCIENCE WORLD

HOW TO TRAVEL FASTER THAN LIGHT

Wormholes, warp drives and other ways to beat the cosmic speed limit *p26*

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Regent Media

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Brain-to-brain messaging *p14*

Robot Swarms
They're just like ants *p36*

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How smartphones affect your health *p57*

On the cover

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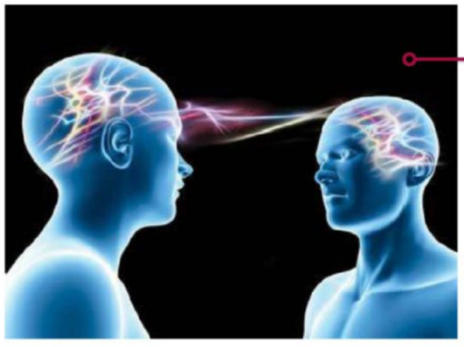
SCIENCE



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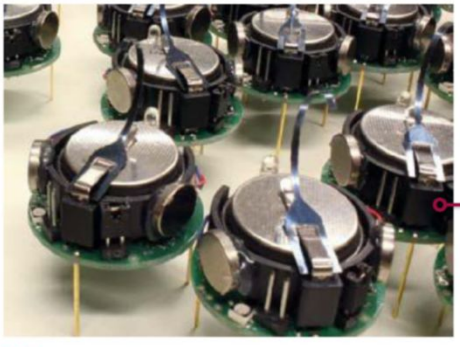

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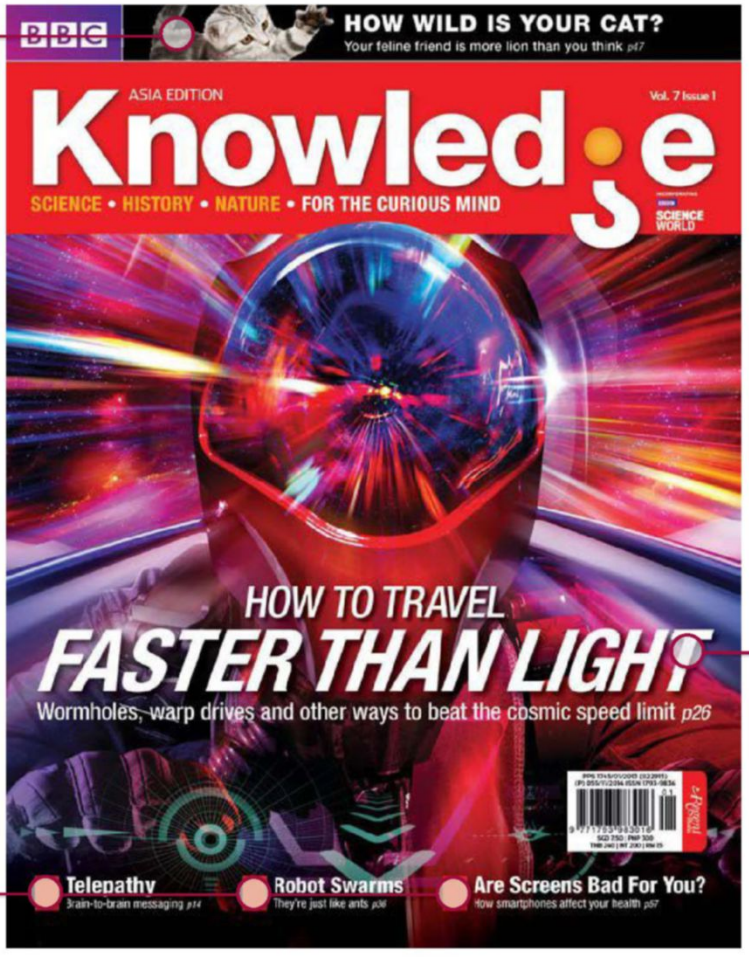

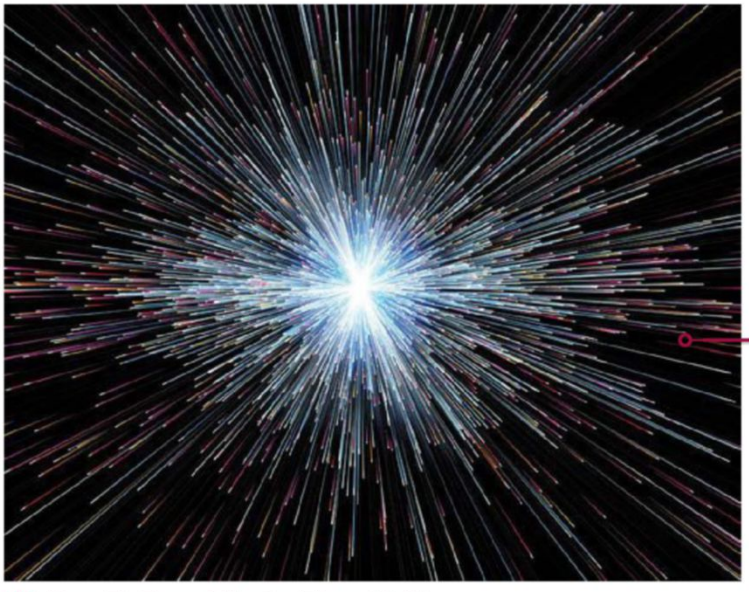

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BBC Knowledge

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DATE: 30 & 31 MAY 2015

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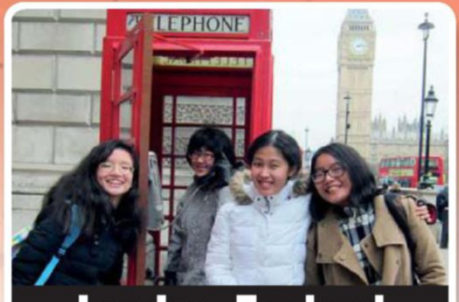

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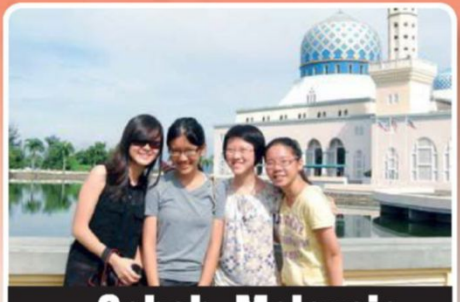

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An educational project organised by BBC Knowledge Magazine to inspire youths and encourage curiosity. The project aims to provide an additional platform for learning through a series of interactive challenges related to Science, History and Nature to nuture and hone students' thinking process.

ELIGIBILITY

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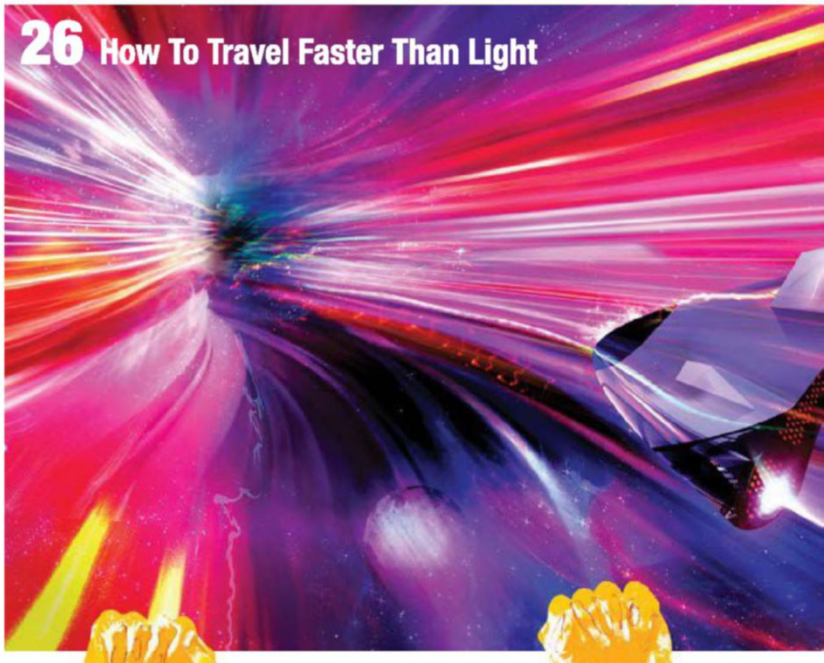

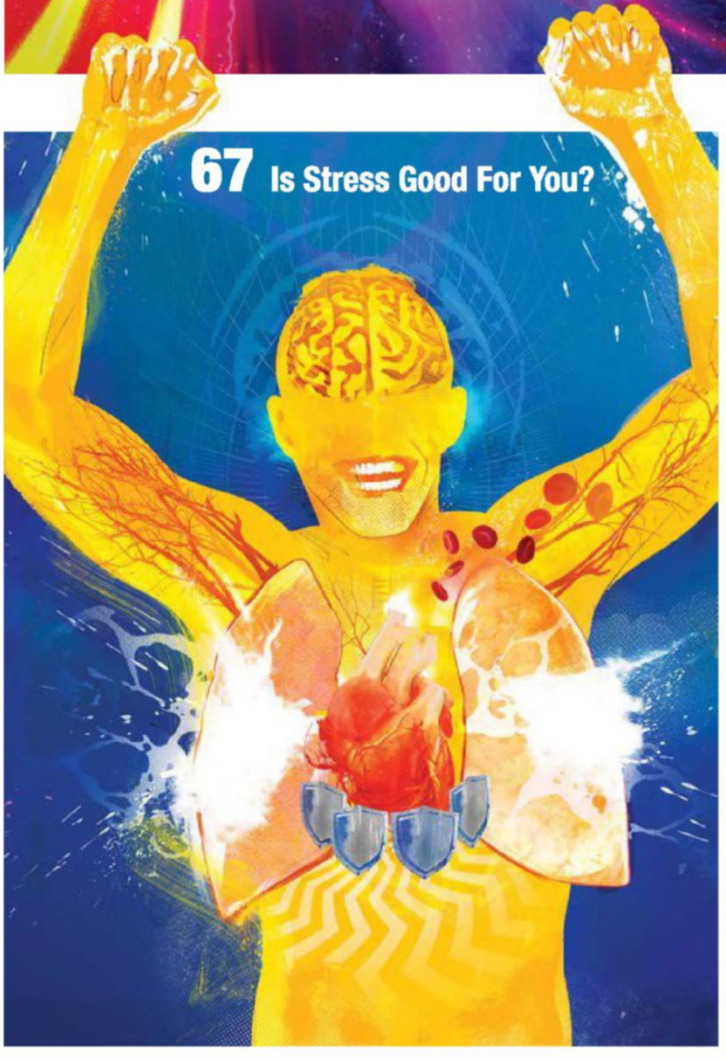

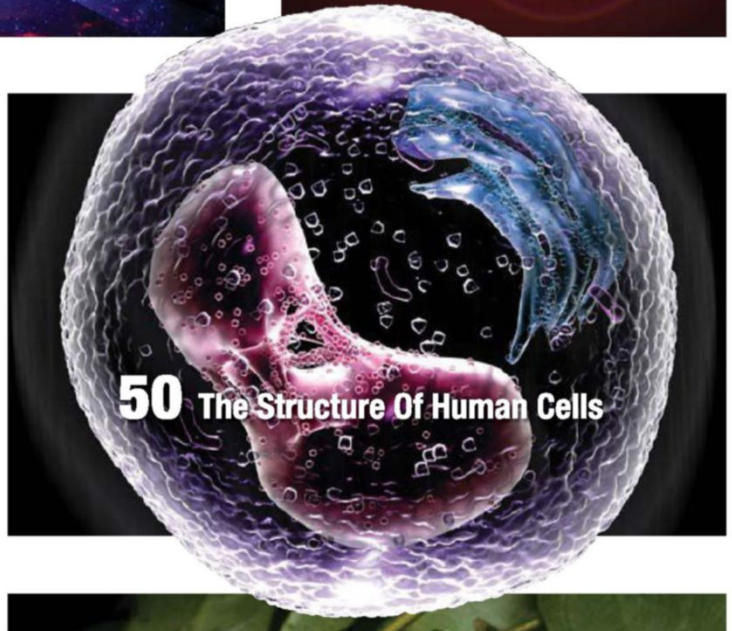

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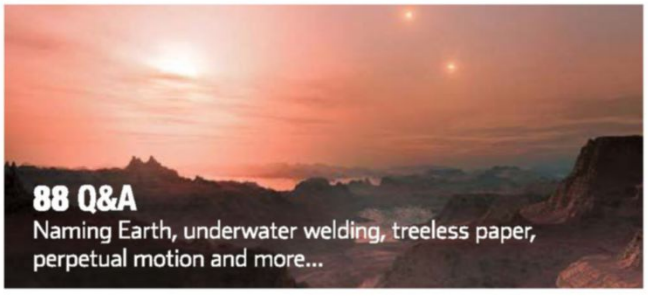

RESOURCE

Welcome

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ENGAGE WARP DRIVE!

Tachyon pulses, warp drives, fusion engines are just some of the propulsion systems used in movies to explore, travel as well as traverse deep space. But in reality we are currently, really far from the tech and know-how needed for interstellar travel.

Sure we have sent probes and landers out to space but to send humans in a spacecraft to go where no man has gone before, presents a whole set of problems. And the main issue for interstellar travel is quite basic really it is the distances involved. Proxima Centauri, the nearest star to Earth is 4.24 light-years away, doesn't sound like much but look at it now as I put it in metric terms, it is 40 trillion kilometres away!

The time it takes and the energy needed to just reach it seems impossible, by current technologies, it just takes too long and there isn't an energy source that is powerful enough, let alone last long enough, for the return journey. However, there is talk that we could tap on wormholes to circumvent this stumbling block, but finding one would be a challenge in itself.

Ben Poon
ben@regentmedia.sg

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Important change:
The licence to publish this magazine was acquired from BBC Worldwide by Immediate Media Company on 1 November 2011. We remain committed to making a magazine of the highest editorial quality, one that complies with BBC editorial and commercial guidelines and connects with BBC programmes.

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Experts in this issue...

Stuart Clark
Stuart is the author of several space-related books, including *Is There Life On Mars?* In this issue he examines the prospects of travelling faster than light (p26).

John Bradshaw
Dr Bradshaw of the University of Bristol studies how humans and animals interact. He's written our felines feature (p47) on why your cat is wilder than you think.

Katherine Nightingale
Katherine is a cellular biologist and a science writer at the Medical Research Council. In this issue she reveals how scientists learned what makes up a human cell (p50).

Holly Cave
Holly is the author of *Really, Really Big Questions About Science.* In this issue, she asks if staring at phone and computer screens adversely affects our health (p57).

✉ SEND US YOUR LETTERS

Has something you've read in BBC Knowledge Magazine intrigued or excited you? Write in and share it with us. We'd love to hear from you and we'll publish a selection of your comments in forthcoming issues.

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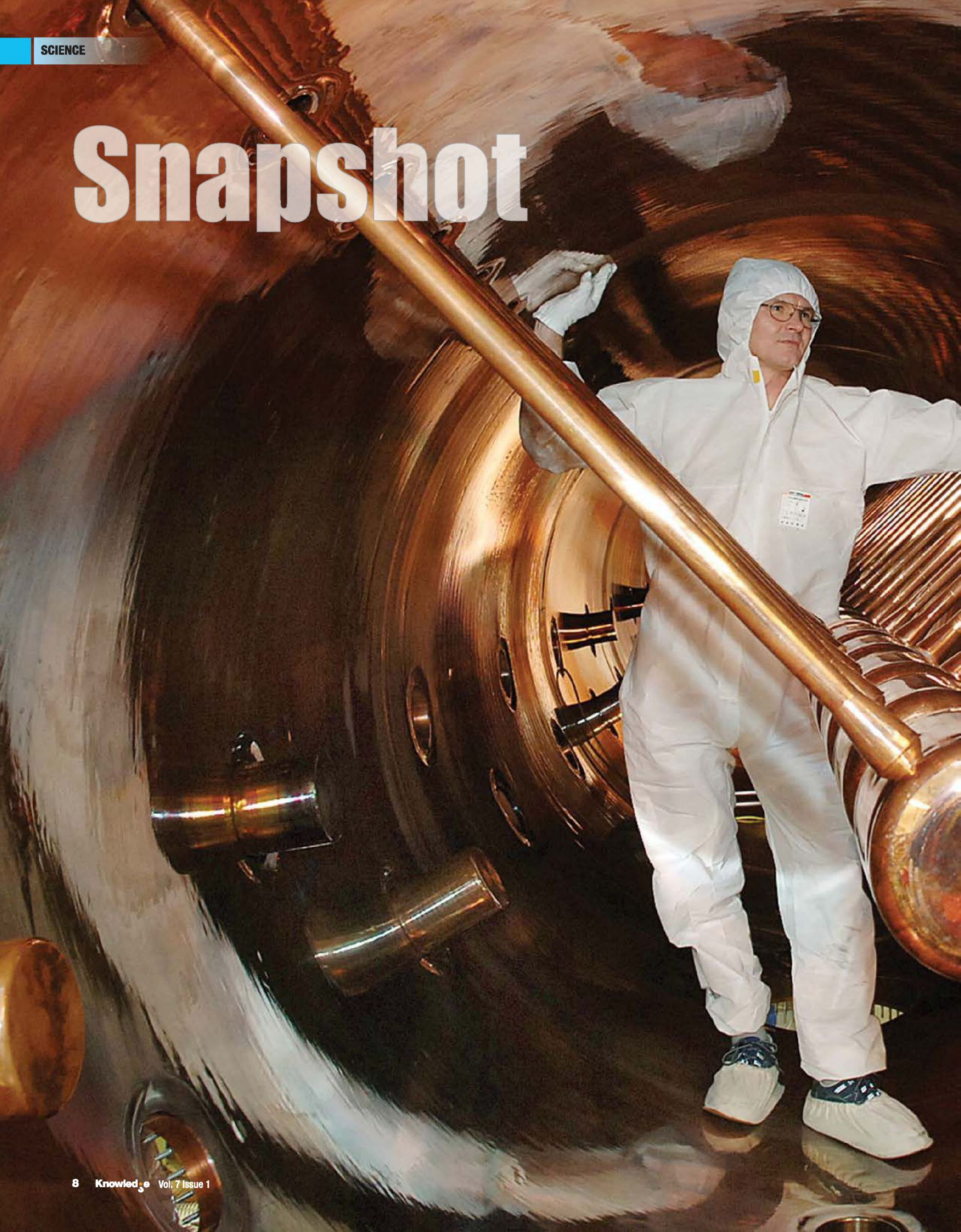
Snapshot



Copper load of that

Inside the belly of this copper-plated beast, atoms are accelerated up to 20 per cent of the speed of light (60,000km/s). Situated at the GSI Helmholtz Centre for Heavy Ion Research near Darmstadt, Germany, the 120m-long UNILAC (Universal Linear Accelerator) is used to accelerate ions – charged atoms or molecules – so that they can be smashed into targets, creating brand new elements.

"The ions shoot through the cylindrical structures that are hanging from the top of the accelerator," says Professor Christoph Düllmann at GSI. "Each time an ion exits one of the cylinders, it picks up a little more energy and becomes a little bit faster."

The accelerator was used to create a synthetic material called element 115 or Ununpentium its temporary name with a temporary symbol Uup – by directing calcium ions at a thin film of the element americium. Similar experiments have allowed GSI scientists to discover six other elements, including hassium, bohrium and copernicium.

PHOTO: G OTTO/GSI

Fake snake

When it comes to crowning the greatest role-player in nature, the snake-mimicking hawkmoth caterpillar has to be in with a shout. That's right – this is actually a caterpillar.

Hemeroplanes triptolemus lives deep in the rainforests of Central America, where its nifty powers of imitation come in handy in the cut and thrust of jungle life. When threatened, the bug draws in its legs and head and expands parts of its rear end to imitate a snake's head. To maintain the illusion, it will even strike out at any attackers – despite being unable to actually bite.

"Snakes are a very strong deterrent for many animals. Some species of monkey are inherently frightened of snakes – even monkeys never exposed to them will respond with alarm to hose pipes," says BBC presenter and entomologist Adam Hart. "But if the snake disguise doesn't work then it doesn't have much to fall back on, although many hawkmoth caterpillars can regurgitate their gut contents, which provides some protection."

PHOTO: DANIEL JANZEN/CATERS

Plastic fantastic

You're looking at one of the most widely used materials on the planet, although you may not recognise it. This almost alien-like landscape is a 1,750x magnified view of a polyurethane, a polymer used in everything from mattresses and trainers to airport seats.

Like any polymer, polyurethanes are made up of repetitive individual units. If you change these building blocks you can vary the properties of the final product: from liquid, through flexible foam, to solid plastic.

"Pictured here is an open cell foam that is only 3 per cent polymer," says Dr Anthony Ryan of Sheffield University. "The key trick in polyurethane foam is to ensure that the bubbles meet and burst just as the polymer solidifies. If they burst before it solidifies, it collapses and shrinks."

Invented by German chemist Dr Otto Bayer back in the 1930s, polyurethanes were first widely used during World War II, commonly as a replacement for rubber, or as coatings on aircraft.

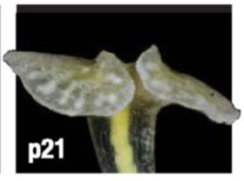
PHOTO: MARTIN OEGGERLI MICRONAUT

Update

THE LATEST INTELLIGENCE

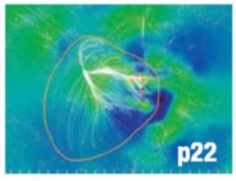
STONEHENGE SECRETS

Archaeologists have discovered exciting monuments at the prehistoric landmark



NEW LIFE DISCOVERED

A strange new life form is baffling scientists



OUR NEW ADDRESS

The Milky Way is part of a galaxy supercluster known as Laniakea

True telepathy is a little way off, but researchers have completed the first step

BRAIN-TO-BRAIN COMMUNICATION

Scientists have managed to allow people to 'talk' to each other telepathically

Can you imagine being able to beam your thoughts directly into the minds of other people? Soon, this fantasy may become a reality. An international team of neuroscientists and robotics engineers has managed to allow brain-to-brain communication between two humans.

PHOTO: SCIENCE PHOTO LIBRARY

One person thinks of a word, which is picked up by the headset (left) and sent over the internet to a receiver (right)

Researchers from Spain's Starlab Barcelona and Axium Robotics in Strasbourg, France have successfully transmitted the simple greetings 'hola' and 'ciao' between the minds of participants located 8,000km (approx 5,000 miles) apart.

"We wanted to find out if one could communicate directly between two people by reading out the brain activity from one person and injecting brain activity into the second person, and to do so across great physical distances using existing communication methods," explains study co-author Alvaro Pascual-Leone. "One such method is, of course, the internet, so our question became, 'Could we develop an experiment that would bypass the talking or typing part of the internet and establish direct brain-to-brain communication between subjects located far away from each other in India and France?'"

It turns out the answer was 'yes'. To do it, the team attached a series of electrodes to the transmitter's scalp to record specific patterns of activity that were triggered when saying a simple greeting. They translated this into binary code and then emailed the results from their base in India to a laboratory in France. A computer-brain interface transmitted the message to the receiver's brain through non-invasive brain stimulation. The 'receivers' experienced this as a sequence of light flashes in their peripheral vision that they were able to successfully decode.

"This in itself is a remarkable step in human communication, but being able to do so across a distance of thousands of miles is a critically important proof-of-principle for the development of brain-to-brain communications," says Pascual-Leone.

The system is currently slow, transmitting only 2 bits of information per minute. However, if it speeds up, future applications could include communicating with stroke victims and sending messages to soldiers in combat.

TIMELINE
A history of brain-to-brain communication

1912
Russian physiologist Vladimir Pravdich-Neminsky carries out the first animal EEG to measure the response of a dog's brain to electrical stimulation.

1924
German physiologist and psychiatrist Hans Berger invents the device known as the electroencephalogram (EEG) and uses it to conduct the very first human EEG. He published his findings five years later.

1976
US researcher Jacques Vidal creates a Brain Computer Interface that lets users guide a virtual object through a computer-generated maze.

2013
A Duke University team achieves brain-to-brain communication between two rats, allowing them to transmit information to one another.

GOOD MONTH/ BAD MONTH

It's been good for:

Pizza lovers

Everyone has a fave pizza topping. But when it comes to the cheese most people are in agreement: it needs to be golden and melted, with the right elasticity. After testing various cheeses, the University of Auckland's Bryony James found Gruyère, Provolone and Emmental came out top. Yet combining one of these with mozzarella gave the perfect balance of elasticity and browning.

Insomniacs

Harvard Researchers have located a neurone in the parafacial zone of the brain stem that is responsible for sending the body into deep sleep. The findings could lead to new medications for sleep disorders and development of safer anaesthetics.

It's been bad for:

Winners

Do you find that you win everything so easily that you get bored? A team at Istanbul's Şehir University has found it's the uncertainty of a close game that creates enjoyment, regardless of the outcome. They had 72 undergraduates play video games against one another. Almost 70 per cent of winners said they would rather play opponents of similar ability than ones they could beat.

People with blood type AB

AB is the rarest blood type, found in just 4 per cent of the population, but a study has found that those with AB blood may be more likely to develop memory loss. A total of 30,000 individuals were followed for 3.4 years on average. People with type AB were 82 per cent more likely than others to develop the thinking and memory issues that can lead to dementia.

PHOTO: GETTY

1 MINUTE EXPERT
Majorana particles

What are they?
As yet undiscovered particles that act as their own antiparticles. They are named after Ettore Majorana, the Italian physicist who proposed them in 1937.

Tell me more!
When most particles confront their antiparticles – particles with the same mass but opposite charge – they annihilate each other and emit energy. It is theorised that Majorana particles do not do this.

Are we any closer to finding them?
University of Surrey researchers have created a method of potentially detecting them, by using photons and superconducting circuits to find Majorana particles' signatures.

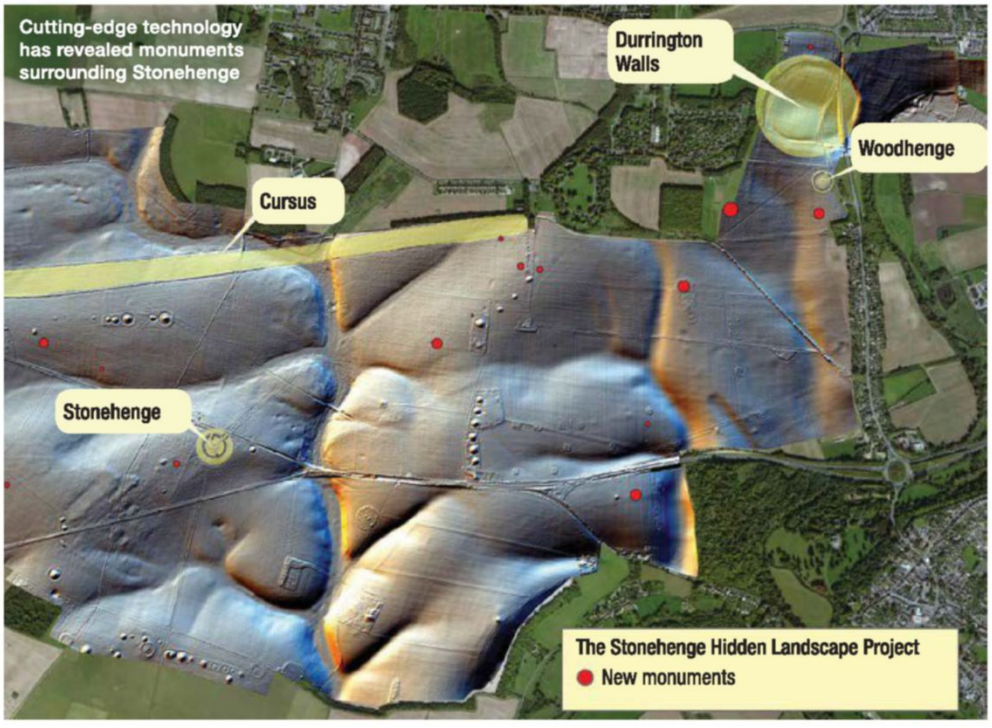
So what can they be used for?
Researchers believe the particles could be of use in the production of functioning q-bits, the building blocks of quantum computers.

Ettore Majorana proposed the particles

PHOTO: LBI ARCHPRO/STONEHENGE HIDDEN LANDSCAPE PROJECT, SCIENCE PHOTO LIBRARY, ALAMY, GETTY ILLUSTRATOR: DEM ILLUSTRATION

Archaeology

Stonehenge site mapped



It's one of the UK's most enigmatic monuments and has puzzled researchers for decades. Now, thanks to a digital scanning project, archaeologists have discovered more about Stonehenge than ever before.

Using cutting-edge remote sensing and geophysical imaging techniques, researchers from Birmingham University have discovered 17 previously unknown monuments surrounding the famous landmark, including burial mounds, circular ditches and an enormous timber building thought to have been used in funeral rituals.

"Despite Stonehenge being the most iconic of all prehistoric monuments and occupying one of the richest archaeological landscapes in the world, much of this landscape in effect remains terra incognita," explains project leader Vincent Gaffney.

The work has revealed prehistoric pits that seem to line up with constellations, as well as Bronze Age, Iron Age and Roman settlements.

The researchers have found that Durrington Walls, the 1.5km-circumference 'super henge' situated close to Stonehenge, was once surrounded by 60 three-metre-tall posts, some of which may still remain beneath the surface.

"This project has revealed that the area around Stonehenge is teeming with previously unseen archaeology and that the application of new technology can transform how archaeologists and the wider public understand one of the best-studied landscapes on Earth. Stonehenge may never be the same again," added Gaffney.

WHO'S IN THE NEWS?

Jack the Ripper
Has London's infamous serial killer finally been caught?

What's he been up to now?
The last murder attributed to him was in 1888. His identity has eluded researchers for over 100 years, but new DNA analysis carried out by scientist Jari Louhelainen has named the killer as Aaron Kosminski, a Polish barber.

DNA found where, exactly?
In 2007, businessman Russell Edwards bought a shawl that was allegedly found at the murder scene of Catherine Eddowes, one of the Ripper's victims. He contacted living descendants of Eddowes and Kosminski, and their DNA matched that on the shawl.

How long can DNA survive?
A 2012 study found that DNA has a half-life of around 500 years, depending on conditions. Theoretically, the Ripper's DNA could have survived. The biggest issue is contamination during storage.

So that settles it, then.
Not quite. Despite Edwards's claims, the work has yet to be submitted for peer review. The shawl's provenance has also been questioned by some.

What lies beneath the Arctic sea ice?

DAVID SHUKMAN
The science that matters

A few years ago I flew on a US Coast Guard plane that was patrolling Alaska's Arctic coast. Over the din of the engines, an admiral shouted into my ear: "My job is to guard the waters around the United States and there's a lot of water where there used to be ice."

The sea ice covering the Arctic Ocean expands and melts with the seasons, but the past 35 years have seen a decline of nearly 14 per cent each decade. As this region becomes more accessible, science is getting dragged into the spotlight.

Research into when the Arctic might be clear enough for new shipping lanes is closely watched, as is work on potential movements of fish stocks. But nothing attracts more attention than studies of the ocean floor.

This year, Canada dispatched two vessels to survey part of the seabed. This kind of activity has huge political and economic significance because the Arctic may hold enormous reserves of oil and gas, and ownership will be decided by mapping.

The stakes were raised in the summer of 2007 when a flamboyant Russian politician used a mini-submarine to plant his country's flag at the North Pole. Moscow's case is that an undersea feature, known as the Lomonosov Ridge, extends from the Russian continental shelf right up to the roof of the world. So, it is argued, any oil and gas up there must be Russian.

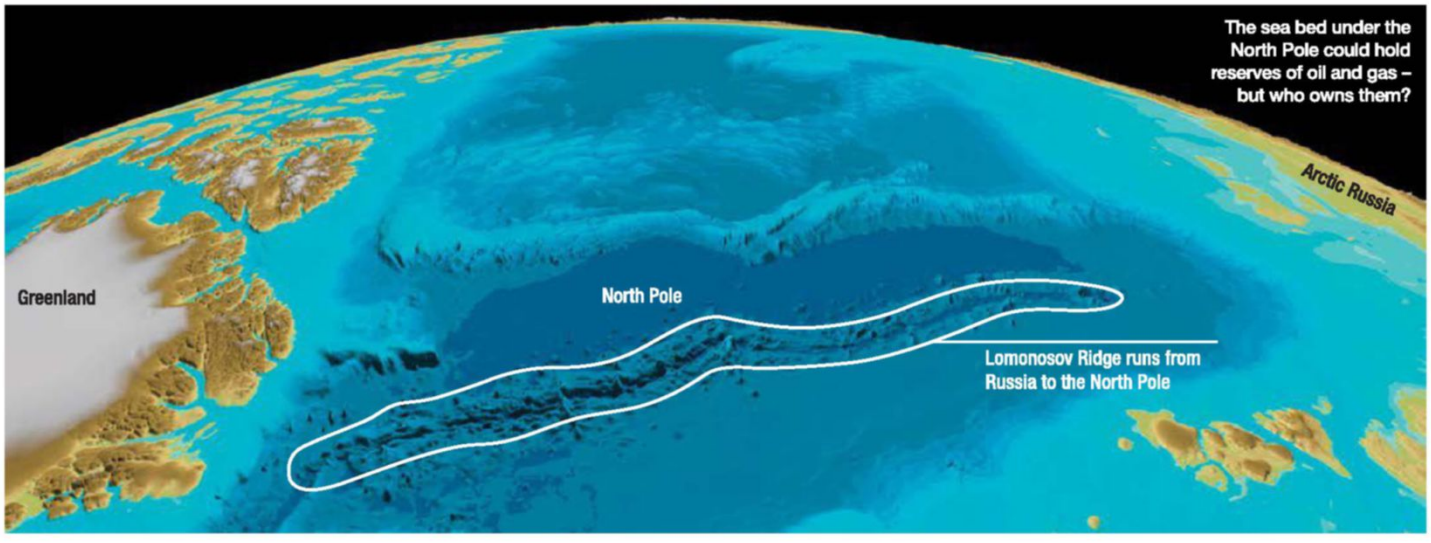
Not so fast, say other countries bordering the Arctic. Denmark, which owns Greenland, also claims a geological connection to the ridge, as does Canada.

So far, this contest is being fought with a combination of rhetoric and research. Each nation's ships are deploying sonar systems and robotic submersibles to build up a picture of the seabed's shape.

The results may show that the Lomonosov Ridge is connected to one country or another, but more likely the results will be a matter of judgement. At some point, the various claims will come before the United Nations. And the geologists involved, more used to polite exchanges at an academic seminar, will find their work under scrutiny.

In this new version of a gold rush, science may come up with answers, but not everyone will appreciate them.

DAVID SHUKMAN is the BBC's Science Editor. @davidshukmanbbc



THEY DID WHAT?!

Birds taught carpentry... by another bird

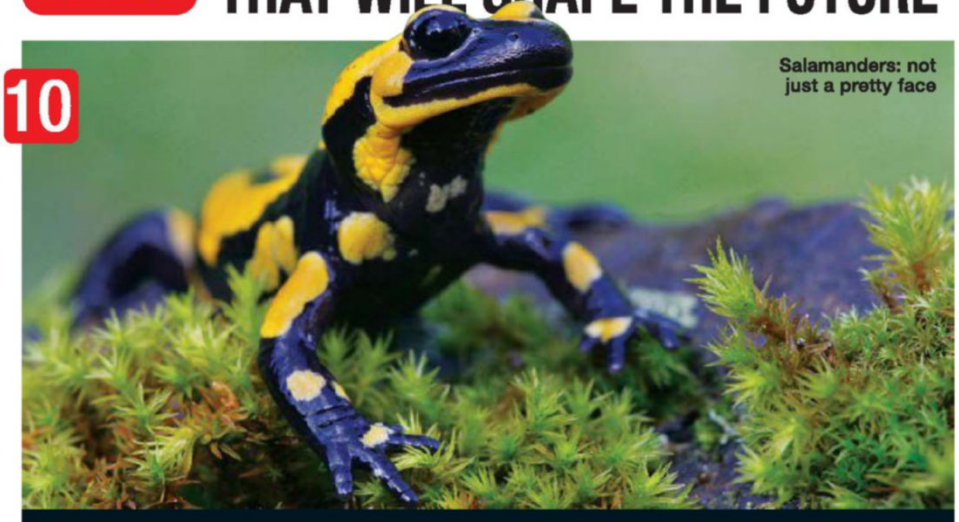
What did they do?
After living at a research centre for two years, a Goffin's cockatoo named Figaro began breaking wooden material into sticks to retrieve food or toys that lay inside a cage. The researchers then had other cockatoos watch his behaviour to see if they could learn it.

Why did they do that?
Many bird species use tools in the wild, but Goffin's cockatoos do not. The researchers wanted to see if Figaro was a one-off or if other cockatoos could also learn how to use tools.

What did they find?
Three of the six cockatoos picked up the skills themselves. They used different techniques to Figaro, suggesting they were not copying his movements but acting creatively. Two of these birds went on to reproduce Figaro's tool-making behaviour.

10 DISCOVERIES THAT WILL SHAPE THE FUTURE

10 Wound-healing ointment

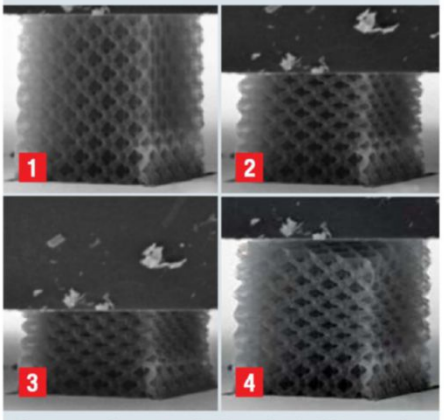


Salamanders: not just a pretty face

Ever cut yourself and wished you could spontaneously heal, Wolverine-style? Studies of a protein taken from the skin of salamanders may result in more effective wound-healing ointments being developed. Tylotoin, a peptide containing 12 amino acids, was found to promote healing when tested on skin wounds in rats. The next step is to test the process on humans.

9 Shatterproof material

Bit of a butterfingers? Fear not, because materials scientists have developed a shatterproof ceramic material that can spring back into its original shape after being dropped. It could be used to create everything from synthetic bone to balloons, researchers say. The material was created by constructing a 3D nanometre-scale lattice. This was done by 'sculpting' solid polymer with a laser. The structure can then be coated with almost any type of material.



Sequence demonstrating how the flexible ceramic can recover after being squished by 50 per cent

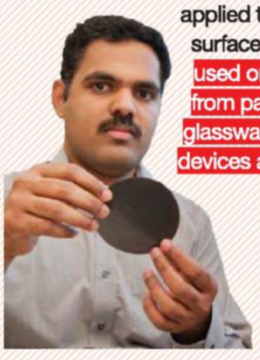
8 Tough robots

Another day in the office for Harvard University's robot

This is Harvard's latest soft robot. But don't be fooled by the word 'soft'. This bot is one tough cookie. Made from silicone rubber backed with Kevlar, it has survived crawling through snow and ice, walking through flames and being run over by a car. Moreover, it is the world's first untethered creation of its kind, meaning it can operate independently under its own power source. Future iterations of the bot could be used in search and rescue missions following natural disasters.

7 Graphene paint

Researchers have found yet another use for wonder material graphene: using it as paint. A team of scientists at Manchester University created a paint made from graphene oxide that forms an incredibly strong, transparent and non-corrosive coating that can be applied to almost any surface. It could be used on everything from packaging and glassware to medical devices and ships.



Dr Rahul Nair with a graphene membrane

6 Fishing nets for greenhouse gas

It sounds like something plucked from the pages of a surreal joke book: researchers in Japan have created a polymer 'net' capable of removing greenhouse gases from the atmosphere. Named PIM-1, the material is peppered with cavities less than 2 nanometres in diameter that capture CO_2 and other harmful gases while allowing other components of air to pass through. The material could potentially cut the cost of capturing CO_2 by 1,000 times, the team says.

Could a net capture the gas from human activities?

PHOTO: ALAMY, LUCAS MEZA/CALTECH, AMIN ARBABIAN/STANFORD ENGINEERING, ALBERT DE WILDE/MINDEN PICTURES/FLPA, UNIVERSITY OF MANCHESTER, THINKSTOCK, HARVARD UNIVERSITY

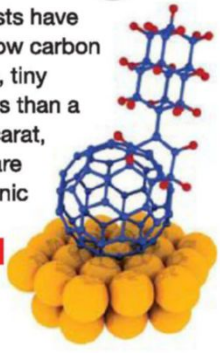
5 Tiny radio chips

Engineers at Stanford University have built an ant-sized radio chip that could make the internet of things a reality. The team has squeezed a functioning radio into single battery-less silicon chip that can harvest energy from incoming radio signals.

This radio could allow appliances to talk to each other

3 Shrunken computers

Stanford University scientists have combined buckyballs, hollow carbon spheres, and diamondoids, tiny carbon cages weighing less than a billionth of a billionth of a carat, to create a diode. Diodes are key components of electronic circuits. The resulting 'buckydiamondoids' could be vital in miniaturising computer chips.



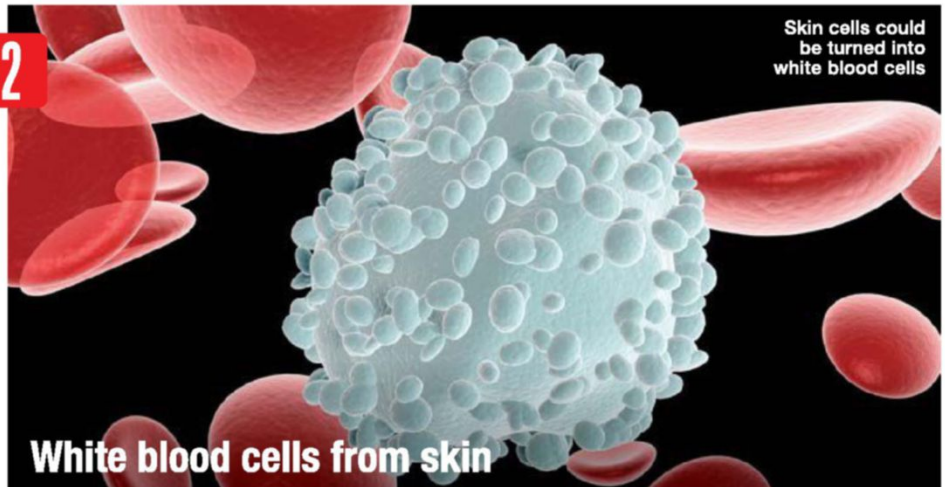
4

Honey has been renowned for its wound-healing properties for centuries

Sweet new antibiotics

A team at Sweden's Lund University has found an unlikely ally in the battle against antibiotic resistance: bees. A group of 13 unique lactic acid bacteria found in fresh honey can effectively counteract a range of infectious pathogens, including antibiotic resistant MRSA. It has so far only been tested for the treatment of wounded horses but if it proves equally successful in human trials, the bacteria could soon find its way into hospitals and pharmacies.

2



Skin cells could be turned into white blood cells

White blood cells from skin

Feeling a bit peaky? Why not use your skin to create some more white blood cells? Scientists at the Salk Institute have figured out a method of transforming regular skin cells into the soldiers of the immune system. Essentially, the skin cells are made to 'forget' what they are by introducing them to a molecule called SOX2. They are then reprogrammed to become white blood cells using a type of RNA. The technique could be used to fight diseases and cancerous cells, therefore enhancing a weak immune system.

1 Waste-eating bacteria

It may be famous for its lush countryside and stately homes, but the Peak District is also home to bacteria that could potentially help in the disposal of nuclear waste. Scientists at the University of Manchester have discovered 'extremophile' bacteria capable of 'eating' chemicals that could otherwise bind with disposed radioactive waste and allow the substances to enter the water supply.

The bacteria was found in soil samples from the Peak District national park

CLICK HERE

New websites, blogs and podcasts

94 Elements

94elements.com

This project aims to tell stories relating to all 94 naturally occurring elements that make up Earth and most of the things on it. Currently, you can hear the touching tale of a patient who remains optimistic despite needing supplementary oxygen for a severe respiratory condition, but more stories are still to come.

New Horizons countdown to Pluto

seeplutonow.com

Pluto may no longer be a planet, but that doesn't make it less interesting. The New Horizons spacecraft was launched in 2006 – just a few months before Pluto lost its planetary status – and is due to reach the ice dwarf and its moon Charon in July 2015. Keep up with the mission here.

Feynman lectures

feynmanlectures.caltech.edu

Whether you're a physics undergraduate or an interested amateur, Feynman's lectures are well worth bookmarking. You'll find all three volumes here, all free and optimised for mobile devices. Feynman gave the lectures to undergraduate students at Caltech in the early 1960s, but they're timeless to this day.

97 Hours

skepticalscience.com/nsh

Ever heard someone say there's no consensus on climate change? Show them this. Created by Skeptical Science, 97 Hours brings together 97 quotes about climate change from 97 scientists who work in the field. The number was from a study that found 97 per cent of climate scientists agree that humans are the main cause of global warming.

PHOTO: ALAMY

Meteorology

Grab an umbrella: weather is set to get more unsettled

It's often said that weather is so unpredictable that it's sometimes possible to experience all four seasons in a single day. Well, if researchers from the University of Sheffield are correct, Britains may soon be experiencing such unsettled weather more and more.

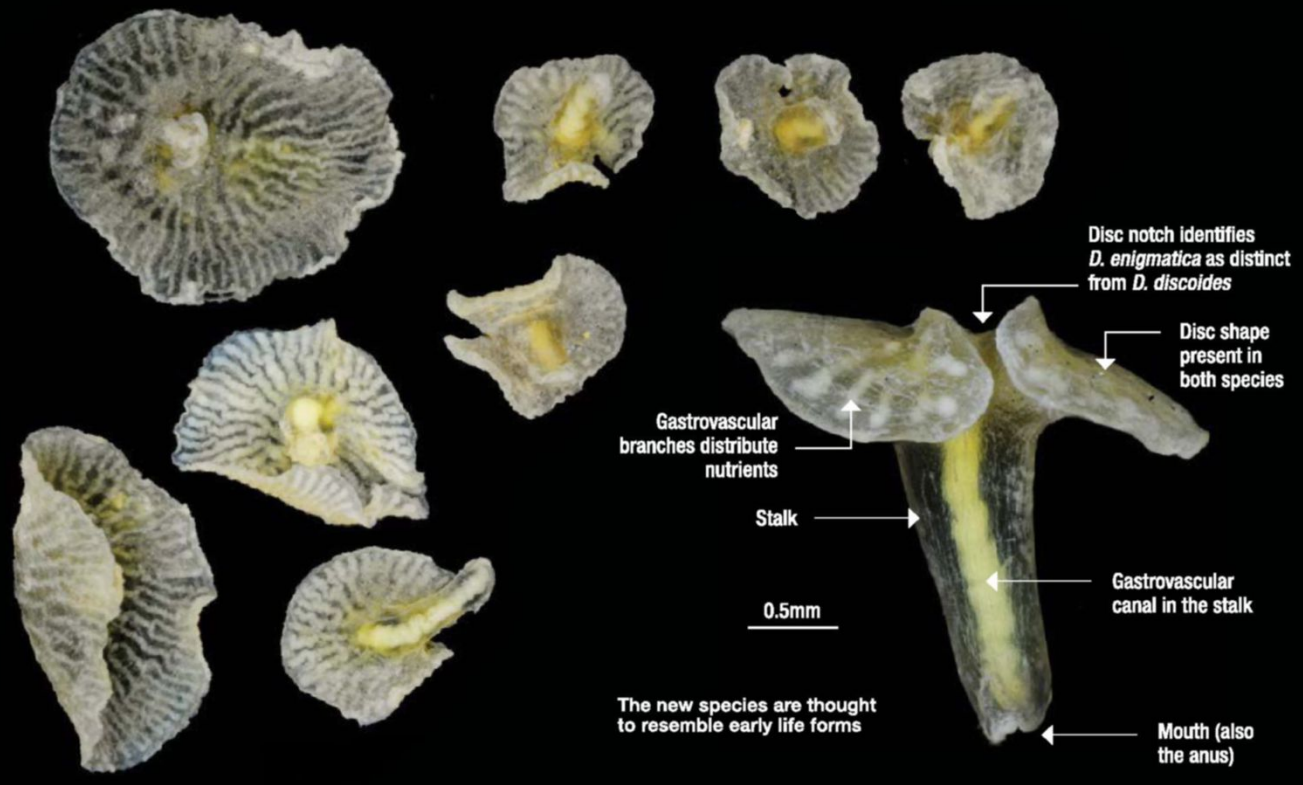
The Sheffield team has found that British winters are becoming more unstable thanks to extreme pressure variations over the North Atlantic – known as the North Atlantic Oscillation (NAO) – ranging from very mild, wet and stormy to extremely cold and snowy. After studying weather data from British winters over the last 115 years, the researchers found that three out of five all-time record high NAO values, and two out of five record lows for December, occurred during the last decade.

"Our study highlights the changing nature of North Atlantic atmospheric circulation patterns that has given the UK more variable winter conditions in recent years," says researcher Prof Edward Hanna. "We cannot use these results directly to predict this winter's weather. But according to the long-term NAO trend we can say that the probability of getting extreme winter weather – either mild/stormy or cold/snowy – has significantly increased in the last few decades. Further research is needed to show whether or not this increased volatility is linked to global warming."

According to researchers, British winters could become far more extreme

Biology

New oceanic life found



They may look like the mushrooms sold in posh delis, but you wouldn't want to put these unusual organisms in your risotto. The tiny fungi-shaped life forms are so unusual that researchers at the University of Copenhagen say they do not fit into any of the known subdivisions of the animal kingdom.

They were collected in 1986, at depths between 400 and 1,000m off the Australian coast, but have only recently been analysed. They were preserved in formaldehyde and stored in ethanol, making them unsuitable for detailed molecular analysis. The researchers say gathering further samples may help them more accurately determine the organisms' relationship to other life.

"Two species are recognised and current evidence suggests that they represent an early branch on the tree of life, with similarities to the 600-million-year-old extinct pre-Cambrian lifeforms, Ediacara fauna," explains University of Copenhagen researcher Jørgen Olesen.

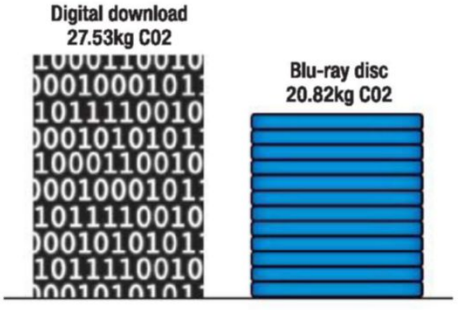
The new organisms are multicellular and have a dense layer of gelatinous material between the outer skin cell and inner stomach cell layers. Scientists have classified them as two new species in a new genus, Dendrogramma enigmatica and Dendrogramma discoides, in the new family, Dendrogrammatidae.

Technology

Discs greener than downloads

It's a question likely to have been asked by every environmentally minded gamer: which format has the bigger carbon footprint, digital download or Blu-ray?

A team led by Kieren Mayers of the INSEAD Social Innovation Centre in France found that Blu-ray discs bought from retail stores are in fact the greener option, as long as file sizes are sufficiently large. The team estimated total carbon emissions associated with Blu-rays and digital downloads for an 8.8GB file that was played for 232 hours. The bulk of emissions came from playing the game, but there was a significant difference between the two formats. Blu-ray racked up 20.82kg of CO_2, while the upper bound estimate of a digital download clocked in 27.53kg.



The carbon footprint of an 8.80GB game on two formats

PHOTO: JUST ET AL

PATENTLY OBVIOUS

Inventions and discoveries that will change the world with James Lloyd

Disney's drone spectacular

If you visit a Disney theme park in the near future, you might be forgiven for thinking that the Mad Hatter has slipped something into your tea. A recent patent application reveals that Disney is planning to populate its parks with blimp-sized marionettes that swoop and sway beneath the command of a fleet of drones.

The unmanned vehicles will be attached to the marionettes by tether lines, which will pull on the characters' arms and legs like hands manipulating humongous string puppets. A control system on the ground will choreograph the drones' movements so that the characters appear to walk, dance and fly through the air.

Two more Disney patent applications detail how the flying vehicles could also carry projection screens in aerial displays, or even be used as 'floating pixels' that flash and glow to simulate fireworks. It promises to be even trippier than a tumble down the rabbit hole.

Patent application number: US20140231590

Digital sandwich boards

Sandwich boards could soon be getting a 21st Century reboot. NomadiX Media is patenting a modern version that supports an LCD screen above the wearer's head. A mounted camera captures images of the audience and sends them to a remote server, where they're analysed. The system then selects a suitable advert for the onlookers, making sure that no old ladies are bombarded with adverts for the latest Slipknot album.

Patent application number: GB2511129

Burglar-proof bike

Bicycle thieves may have met their match. Three engineering students in Chile have come up with what might be the world's first unstealable bike. The clever idea behind their Yerka Project is to make the lock an integral part of the bike's frame. To securely lock up the bike, the down tube is divided into two and rotated by 90°; then the seat post is taken out and threaded through. A would-be thief would need to break the bike in order to steal it, effectively rendering it useless.

Patent pending nadiemelaroba.cl

PHOTO: THINKSTOCK, DANIEL POMAREDE/IRFU ILLUSTRATOR: DEM ILLUSTRATION

Space

Milky Way's new address

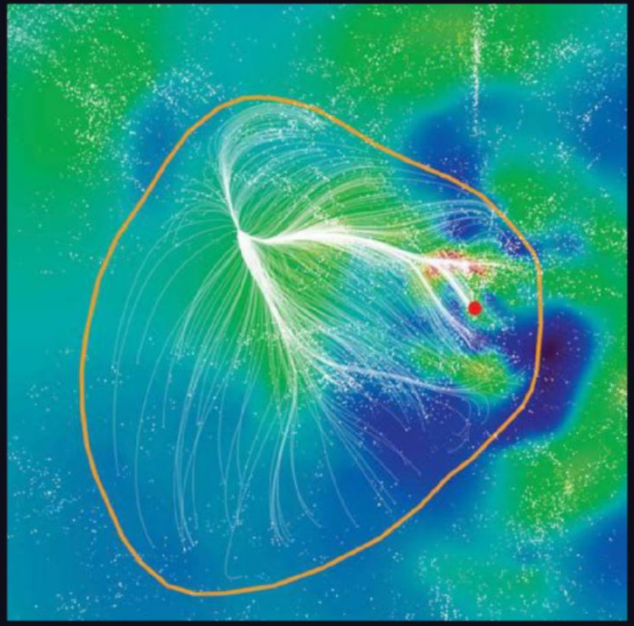
The Milky Way is actually part of a much larger group of galaxies

The more pernickety among us might want to update our address books: astronomers have determined that the Milky Way is part of a huge, newly identified supercluster of galaxies dubbed Laniakea.

Researchers made the discovery by piecing together data from several radio telescopes, including West Virginia's Green Bank Telescope, to form a detailed 3D map.

Superclusters contain dozens of galaxies, making them among the largest structures in the known Universe. They are so big that the gravitational forces they generate affect the motion of nearby galaxies. By measuring the velocities of galaxies throughout our local Universe, the researchers were able to determine their positions.

The Laniakea supercluster is 500 million light-years across, contains in excess of 100,000 galaxies and has a total mass of 100 million billion Suns. Its name means 'immense heaven' in Hawaiian. "We have finally established the contours that define the supercluster of galaxies we can call home," said lead researcher R Brent Tully. "This is not unlike finding out for the first time that your hometown is actually part of much larger country that borders other nations."



Laniakea is contained in the orange circle; the Milky Way is the red dot

Clouds don't just form interesting shapes - they're huge power stations too

For the past 15 minutes I've been staring out of the window, looking up at fluffy white clouds. They're floating eastwards, and though it's calm down here it's clearly rush hour up there. They're shape-shifting as they go. Just now, I saw a frog tip over until it became a human face that turned into a hat. Then I started thinking about it and almost gave myself vertigo. It wasn't the physical scale of the clouds, or the fact that all these tonnes of liquid water are happily floating 3km off the ground. It was the thought of the torrent of energy that all this represents, that's whooshing about above our heads every day.

Imagine a water molecule that's just evaporated from my cup of tea. It's got enough energy to float away from the cup and join the jostling masses of oxygen and nitrogen molecules and others that make up our atmosphere. They're all sharing energy by playing bumper cars – each molecule collides with another one about a billion times each second. Our water molecule finds itself in a puff of warm air, sliding upwards through the atmosphere like an invisible hot air balloon. As the balloon rises, it expands and cools, and the jostling molecules slow down a bit. There is dust in the balloon as well, and occasionally our water molecule settles on to one of the dust particles. But it has enough energy that it soon escapes and joins the bumper cars again.

About 3km up there's a sudden change that betrays some secrets. The molecules have cooled and slowed so much that when our water molecule sticks to a dust particle, it doesn't always have enough energy to escape. This is the start of a liquid droplet, and this water molecule will soon be joined by others. Condensation begins, and a cloud is born. The hidden air packet has revealed itself.

And here's where the energy really starts to play a role. It takes energy for a water molecule to remain as a gas, and when it condenses on to the dust, that energy is given up and makes everything around it warmer. The quantity is vast. Think about the energy your kettle uses to heat 1 litre of water from 0°C to 100°C. To convert the same amount of liquid into gas, it takes five times as much energy as the kettle, even though the temperature doesn't change. And when the water condenses, it gives the energy back. The forming cloud has billions of tiny droplets of liquid water condensing from water vapour, each giving off heat energy. Our hot air balloon is suddenly supercharged with the energy of millions of kettles, so it warms, expands and rises faster, climbing up to the top of a cloud. This one air packet makes a puff - one of those familiar friendly puffs on the tops of cumulus clouds - and then runs out of energy for the time being.

Water molecules from a cup of tea eventually join their friends in the clouds for a game of bumper cars

"An average cumulus cloud might have 1,000 tonnes of liquid water in it. It's a monstrous amount of energy to play with"

An average cumulus cloud might have 1,000 tonnes of liquid water held within it. It's a monstrous amount of energy to play with, and it's only a fraction of the total in the cloud (the rest is gas).

The formation of a cloud lets us glimpse the churning of the atmosphere. That's why these clouds are always changing shape – air is constantly bubbling up from below, briefly becoming visible as it shifts energy around via water, and then sinking back down. Never mind frogs and faces and hats. Next time I look at cumulus clouds, I'll see them for what they are - a tiny part of the vast engine of our atmosphere.

DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter whose most recent series is *Super Senses*

ILLUSTRATOR: ANDREW LYONS

Destination ZeroCarbon®

ECO-IMAGINEERING EDUCATION

Celebrating and empowering the spirit of eco-Imagineers

By Marina Chong

Destination Zero Carbon (Singapore) Finals 2014 was held recently at the Stephen Riady Centre of University Town, National University of Singapore (NUS) and attracted 75 teams from secondary schools, including three overseas teams and tertiary institutions. 3D ClassWorks with the NUS, Department of Mechanical Engineering, Faculty of Engineering and Ngee Ann Polytechnic, Mechanical Engineering Division jointly organized the event.

What's new for this year's race was the use of mobile phones as remote controls for a mini 'F1' race. The students also had to up their game from last year, as there was an increase of participants from tertiary institutions. During the event, Renault thrilled everyone present with its eco-friendly electric car, Twizy. Yet to be available for public roads, the Twizy is a battery-powered two-passenger electric vehicle designed as well as marketed by Renault and manufactured entirely in Spain.

During the event, Mr Kunhimohamed, CEO of 3D ClassWorks announced that DZC is undergoing major restructuring and will be repositioned as a community-based and sustainability-focused, non-profit organization. This move would enable it to effectively meet the holistic educational needs of youths globally. Nurturing their positive traits and promoting individual and societal successes through character building activities and programmes.

With this change it will profoundly alter the competition format, which was created four years ago. He envisages the competition to be even more exciting with this quantum leap taken by the new community-based DZC. This new DZC concept is now being piloted in other regions such as Hawaii, Indonesia and Saudi Arabia.

Jointly Organised by:

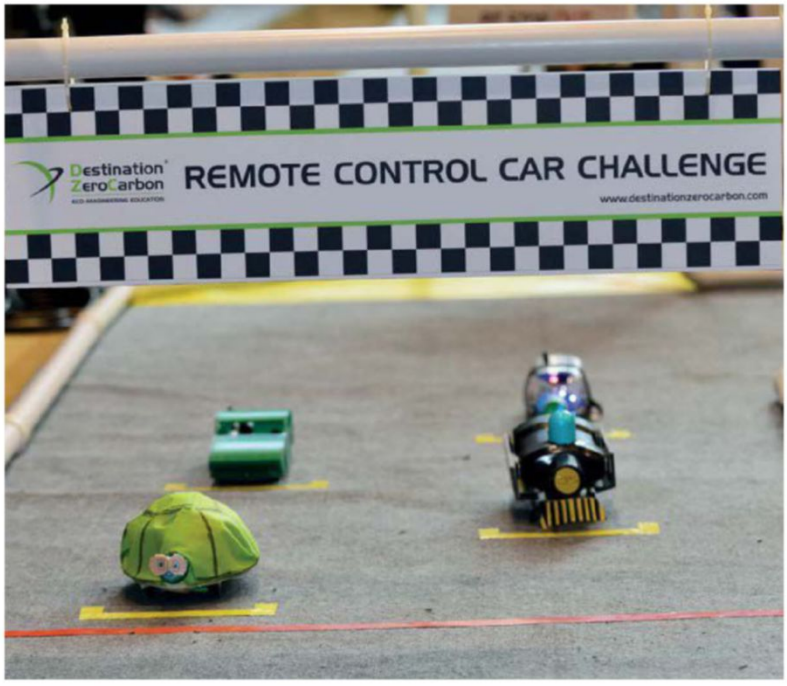
3D ClassWorks, NUS National University of Singapore, Ngee Ann Polytechnic

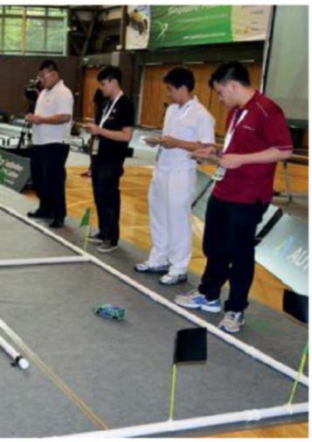
Sponsors:

AUTODESK., DNV·GL

Partners:

Singapore Environment Council, Renault, Intex Pack, Knowledge, Regent Media





Exclusive Focus On The Environment

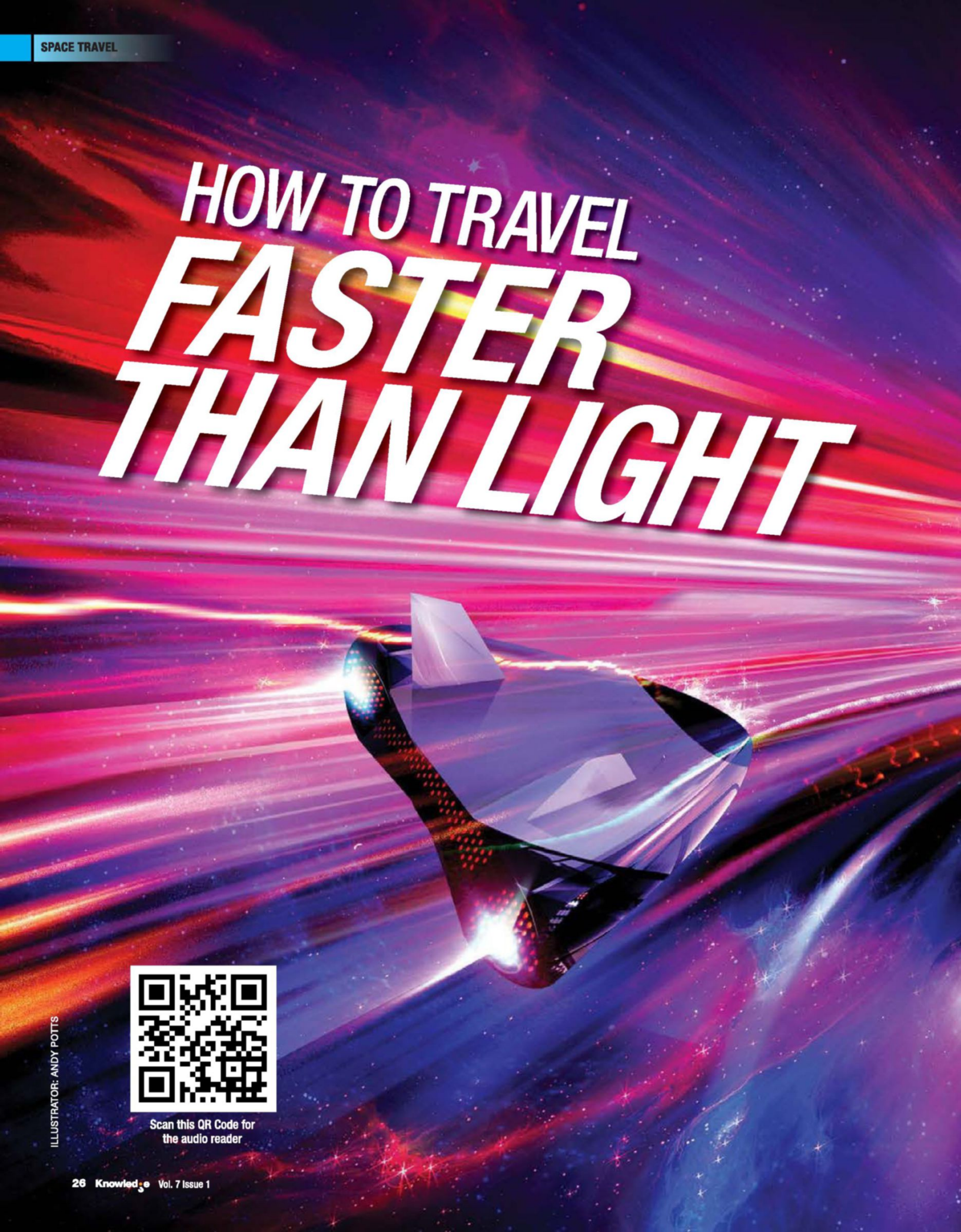
DZC is a green education programme cum race league which features 'design-build-race' 1:20 scale zero carbon emission powered drag race cars. The programme incorporates relevant contents in Mathematics, Physics, Design & Technology, Chemistry and Geography.

DZC features the use of alternative clean energy as an effective approach to reduce carbon emission into the environment. Developed to instil greater interest in Science, Technology, Engineering and Mathematics (STEM) education, DZC programme hopes to mould students with the right values and skills so that they would grow to become resourceful workers and responsible eco-citizens of the world. (www.destinationzerocarbon.com)

Results

DZC Overall Champion (Post-Secondary):
Axle (ITE College Central)
DZC Overall Champion (Secondary):
E-hEART (Regent International School, Kedah)
DZC Race Award (Champion, Post-Secondary):
Hydroxy Wave (ITE College East, Electronics)
DZC Race Award (Champion, Secondary):
Fast & Furious (Ping Yi Secondary School)
DZC Car Styling Award (Champion, Post-Secondary):
Axle (ITE College Central)
DZC Car Styling Award (Champion, Secondary):
E-hEART (Regent International School, Kedah)
DZC Energy Efficiency Challenge (Champion, Post-Secondary):
Axle (ITE College Central)
DZC Energy Efficiency Challenge (Champion, Secondary):
CHS Team 1 (Catholic High School)
Innovation Award (Champion, Post-Secondary):
Hermes Turtle (River Valley High School)
Innovation Award (Champion, Secondary):
Protium (River Valley High School)
DZC Green Car Award (Champion, Post-Secondary):
Cubiod 3D (ITE College East, Electronics)
DZC Green Car Award (Champion, Secondary):
PHSS Team 2 (Pei Hwa Secondary School)
DZC Best Presentation Board (Post-Secondary):
Axle (ITE College Central)
DZC Best Presentation Board (Secondary):
E-hEART (Regent International School, Kedah)
V-Clip Award (Champion, Post-Secondary School):
D-CEG (Singapore Polytechnic, EEE)
V-Clip (Champion, Secondary):
Synergy 5 (Robotix, India)

HOW TO TRAVEL FASTER THAN LIGHT



Scan this QR Code for the audio reader

ILLUSTRATOR: ANDY POTTS

The movie *Interstellar* depicts humans exploring deep space. Stuart Clark investigates the possibilities of rapidly traversing the Universe using wormholes, warp drives and a mysterious substance called negative energy

You're all packed and waiting in the departure lounge. You've checked your passport for the umpteenth time, you're wondering what the in-flight film will be, and although long-haul is not your favourite, it will all be worth it when you get there. But you are not going a few thousand miles to reach another continent. Instead, you are stepping aboard a starship that is going to travel a few thousand light-years.

The dream of interstellar travel is one that most of us have had at one time or another. It's a common theme in sci-fi movies: trips to distant worlds, journeys into black holes, or salvation for the human race away from the dying Earth. The latter is the premise of director Christopher Nolan's latest film Interstellar, in which a group of astronauts use short-cuts through space and time, called wormholes, in order to find habitable worlds across the cosmos.

The biggest problem encountered when contemplating interstellar travel is the vast distances involved. The nearest star to us is Proxima Centauri, which is 40 trillion kilometres away. That's the number four followed by 13 zeroes! Given such unwieldy numbers, astronomers have created the light-year. A light-year is the distance that a beam of light can travel in a single year and is the equivalent of 9.5 trillion kilometres. On this scale, Proxima Centauri is 4.2 light-years away.

Astronomers choose the speed of light because it is the fastest thing in the

"I'd have to say that wormholes are a pretty tough proposition"

Stephen Hsu, physicist at Michigan State University

Universe. Experiments in the 19th and 20th centuries showed that the speed of light appeared to be an absolute limit on how fast you can travel through space.

The fastest spacecraft ever made were the European Space Agency's Helios probes. In the mid 1970s, they flew past the Sun at a speed of more than 70,000 metres per second. That's nothing compared with light, which travels at 300 million metres per second. Even if we could travel at the speed of light, it would still take 4.2 years to travel to the nearest star. And it would just be the nearest star. Most are hundreds, thousands, or even hundreds of thousands times farther.

If we are ever going to make interstellar travel a practicality, we are going to have to find some way of circumventing this absolute speed limit. That's where wormholes come in. "Wormholes are a fundamental topic in general relativity," explains physicist Stephen Hsu of Michigan State University.

Mapping space

General Relativity is Albert Einstein's description of the Universe. It provides a coordinate system called space-time, in which all celestial objects are placed. Space-time is often described as a continuous fabric that stretches throughout the Universe. When you move around in space-time, you're moving in both space and time. Celestial objects warp this fabric, and while this warping is largely invisible to us, it creates the force of gravity and deflects rays of light.

Launched in 1974, Helios became the fastest spacecraft

"Wormholes are a fundamental topic in general relativity"

Stephen Hsu, physicist at Michigan State University

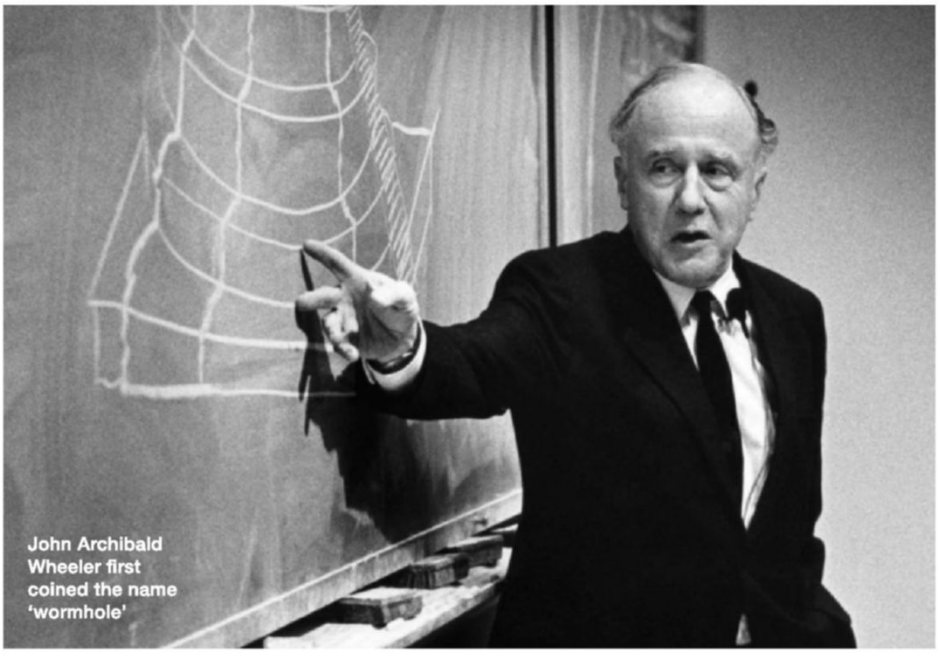
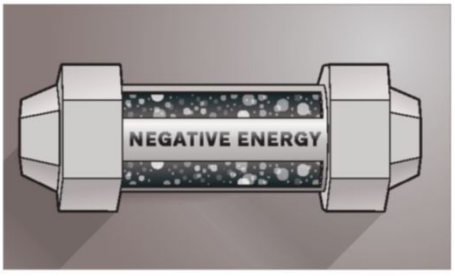

John Archibald Wheeler first coined the name 'wormhole'

PHOTO: NASA/KSC, SCIENCE PHOTO LIBRARY X2 ILLUSTRATOR: ACUTE GRAPHICS

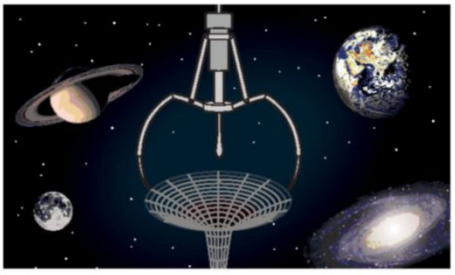
HOW TO BUILD A WORMHOLE

By combining sophisticated technology with a dash of negative energy, we could create wormholes to traverse space and time



1 Get negative energy

The first step is to find a source of strong negative energy to counteract the tendency for a naturally created wormhole to collapse. This energy must be stored in a way that overcomes its tendency to make space-time expand around it. This would involve advanced tech and there's no guarantee that the correct negative energy exists.

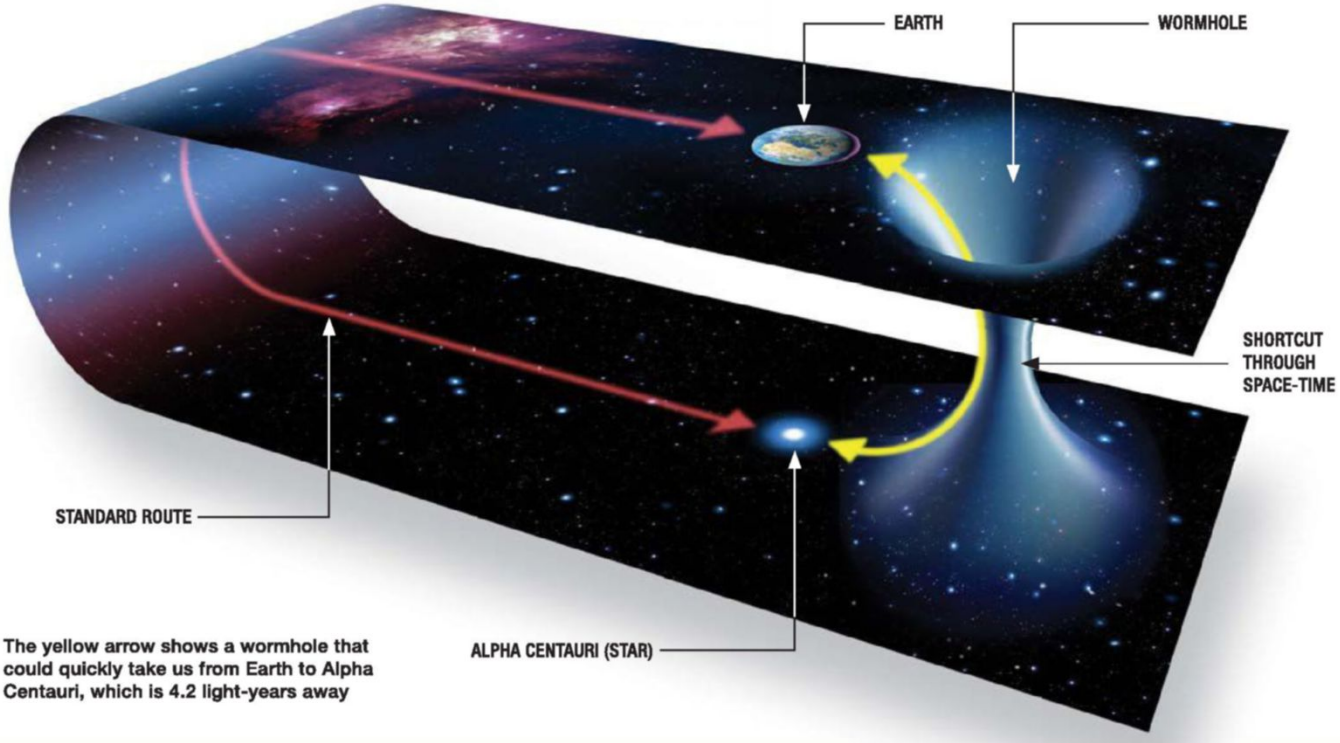


2 Find a wormhole

Wormholes are likely to be constantly forming and disappearing on the Universe's smallest scales. Quantum foam is the space-time continuum seen through an ultra powerful microscope or particle detector. A highly sophisticated piece of technology would have to grab a sub-microscopic wormhole by the throat.

SPEEDY SHORTCUT

Wormholes have been discussed by scientists for nearly a century and could be the secret to hopping through space – the trouble is, it's uncertain if they could definitely be built



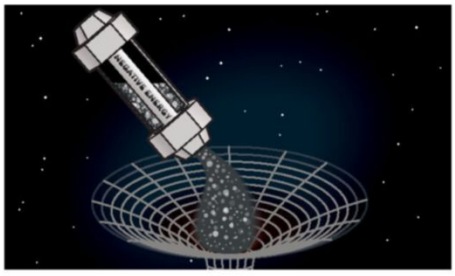
The yellow arrow shows a wormhole that could quickly take us from Earth to Alpha Centauri, which is 4.2 light-years away

Wormholes are tunnels through space-time; think of them as shortcuts that stop you having to travel the long way round through space. The name was first coined by John Archibald Wheeler in a 1957 article for the journal Annals of Physics. Einstein himself investigated the possibility in 1935 with his colleague Nathan Rosen, while German mathematician Hermann Weyl proposed their existence the decade before.

Based upon the mathematics of black holes, Einstein-Rosen bridges, as the wormholes were called, appeared to be sub-microscopic structures. They also seemed to be naturally unstable.

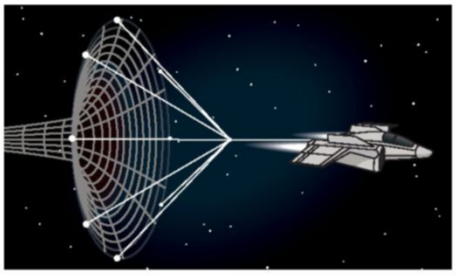
WHAT IS SPACE-TIME?

Space-time is the coordinate system Einstein used in General Relativity. Time is treated as no different from three-dimensional space. No one knows if space-time is a mathematical structure, or physically real. Attempts to detect space-time's structure have failed, but it's still early days.



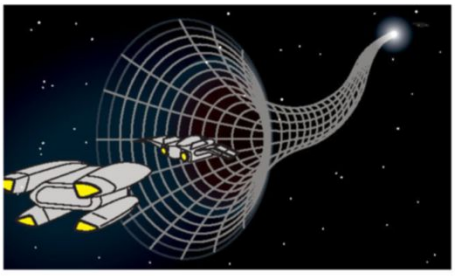
3 Easy does it

Once the wormhole had been stabilised with a shot of negative energy, a space probe would have to be sent through to see where it ended up. If it led nowhere useful, or somewhere dangerous, then it could simply be left to decay away again. But if it formed a beneficial bridge, then the task of injecting more negative energy into it would begin.



4 Shortcut through space

Once the wormhole was large enough, it could begin to be used by traffic. There may also be the possibility of moving the entry and exits into better locations. All that would be needed is some sort of space tug that used the antigravity force of negative energy to 'push' the wormhole's openings into more beneficial positions.



5 Cosmic motorways

Eventually, a wormhole network could span the Galaxy and beyond. It may even be possible to tunnel into other universes, if they exist. Since wormholes are shortcuts through space-time, they may be able to be used as time machines. But you would never be able to go back to a time before the wormhole was created.

So while it is possible that sub-microscopic wormholes are forming continually, they are collapsing before anything can pass through them.

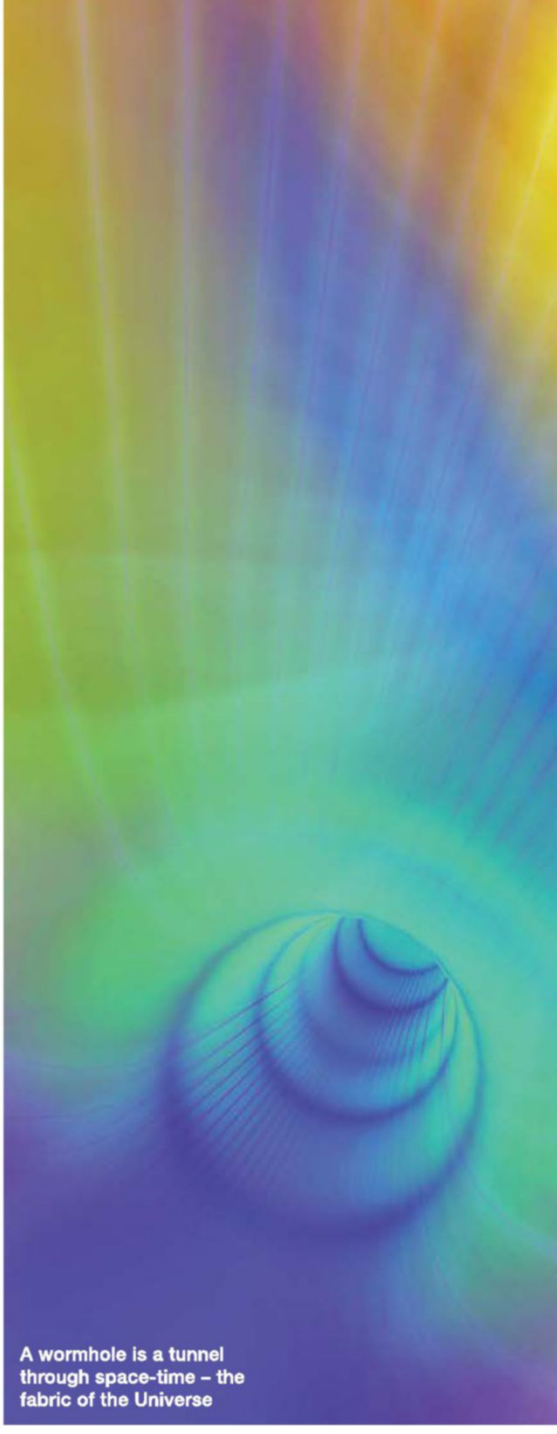
Skip forward to 1988 and the work of physicist Kip Thorne of the California Institute of Technology. Thorne found that if the right kind of energy could be introduced into the wormhole at the moment of its creation, the tunnel could be stabilised and enlarged, therefore making it traversable. And hey presto: interstellar travel! Except that there is a problem, and it's to do with the energy that's required. "It is unlike anything that we actually know about in the Universe," states Hsu.

The problem is that it has to exert what's called 'negative pressure'. To do that, it must be some kind of negative energy or mass, capable of creating a force of anti-gravity. In 1997, astronomers discovered that the expansion of the Universe was accelerating. They decided that this was happening because space is filled with a kind of negative energy that is causing the expansion to speed up.

They called it 'dark energy', but not even that fits the bill for wormholes. "It's even weirder than dark energy," explains Hsu. Nevertheless, he began calculating the precise details of what this energy would do to the wormhole. It wasn't good news.

The energy would follow the strange laws of quantum mechanics, which operate on the smallest scales. The upshot is that its position and momentum could not be precisely determined, so the wormhole would be 'fuzzy'. "There would be some uncertainty about where or when you would end up if you went through it," says Hsu. In other words, yes you could take a shortcut through space-

Stephen Hsu believes something weirder than dark energy is behind wormholes
Below: The *Interstellar* movie poster



A wormhole is a tunnel through space-time – the fabric of the Universe

PHOTO: DERRICK L TURNER/MICHIGAN STATE UNIVERSITY, SCIENCE PHOTO LIBRARY, MOVISTAR/WIKI, NASA

HOW TO FIND A WORMHOLE

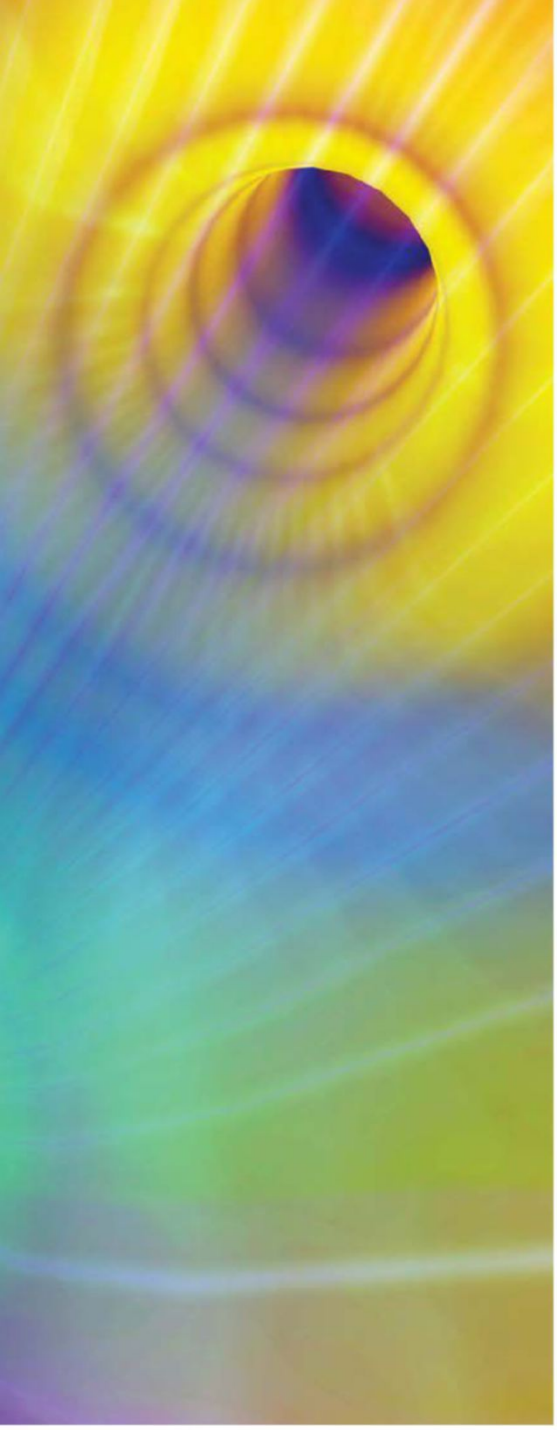
Locating a wormhole in the depths of space is a pretty tough proposition, but there are several theoretical ideas about what to look for...

It may be possible to see stars from the other end of the wormhole shining through the conduit. Alexander Shatskiy of Moscow's Lebedev Physical Institute calculated that the negative energy needed to open up the wormhole will push light into a halo coming from the edges of the wormhole.

Shatskiy suggested that a gamma-ray burst (GRB) taking place on the other side of the wormhole could give it away. Astronomers would be able to see a GRB but would fail to identify a host galaxy in which it took place.

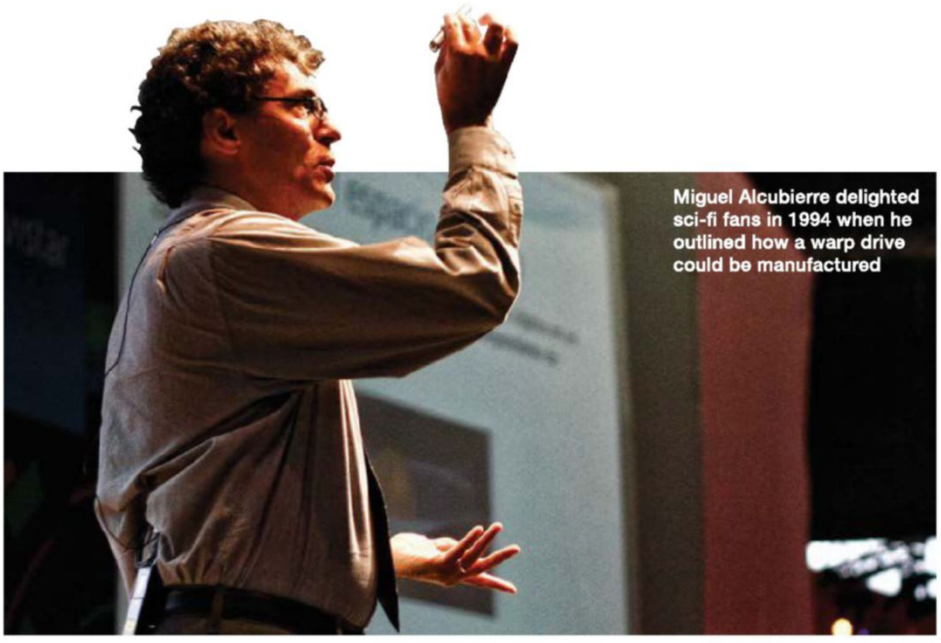
Another thought is that the mouth of the wormhole could drift across our line of sight in front of a star. The strong gravitational field

An artist's impression of a gamma-ray burst – it could be used to detect a wormhole



of the wormhole would first amplify the star's light, through a process known as gravitational lensing. The star would dim as its light disappeared down the wormhole. Finally, the starlight would spike again in another gravitational lens effect, as the wormhole moved off the star. This would be a recognisable signature of a wormhole.

Perhaps the most important aspect of identifying a wormhole is the implication that extraterrestrial beings must exist. A wormhole large enough to be visible is probably only possible because some enterprising – and highly advanced – life form has managed to engineer it.



Miguel Alcubierre delighted sci-fi fans in 1994 when he outlined how a warp drive could be manufactured

time. But you wouldn't be able to control the destination or the time of arrival.

For Hsu, this all adds up to one result: "I'd have to say that wormholes are a pretty tough proposition and certainly way beyond any technological capabilities that we are going to have in the foreseeable future."

So wormholes may remain the preserve of fantasy. Indeed, their early champion Kip Thorne is a consultant on the Interstellar movie. But what about that other bastion of sci-fi: the warp drive?

Star surfer

In 1994, Mexican physicist Miguel Alcubierre made his name by showing theoretically how a warp drive could be constructed. He solved Einstein's equations to show precisely how a bubble of space-time could be engineered in such a way that a spacecraft could surf this wave at arbitrarily high speeds.

The sticking point is that it again relies on some kind of negative energy to warp space and provide the anti-gravity force to push the spacecraft around.

NASA's Johnson Space Center in Houston, Texas, is home to a small team of scientists and engineers who work in the Advanced Propulsion Physics Laboratory. Under the guidance of engineer and physicist Harold 'Sonny' White, they replicate experiments that others claim show unexpected properties that could be used for future propulsion. The NASA team hit the headlines and controversy in summer 2014 when they appeared to publish results corroborating that an "impossible" drive system could work.

The system was originally called the EmDrive and was invented by British aerospace engineer Roger J Shawyer. Shawyer believes that microwaves directed into a conical cavity can produce a thrust under the right conditions.

His work has been savagely attacked by physicists who point out that it violates the conservation of momentum, an underlying principle in physics. However, a number of other research teams, including that of White, also seem to have measured a thrust in re-constructed experiments.

"It is clear that the theory of relativity is not the last word. But all the rest is speculation"

João Magueijo, professor of physics at Imperial College London

WHAT IS NEGATIVE ENERGY?

Negative energy is a hypothetical substance that would generate an anti-gravity force. It is linked with exotic matter, another hypothetical substance, which possesses properties that have never been observed in the lab. No one knows if these substances exist, or are just mathematical possibilities.

3 THINGS THAT ARE FASTER THAN LIGHT

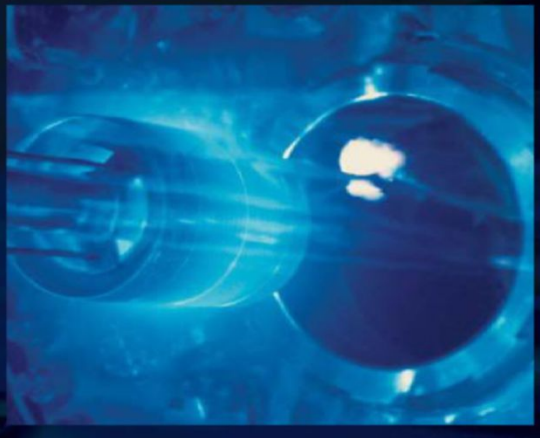
We grow up believing that nothing in the Universe can move faster than light, but this trio of physical oddities can beat photons to the finishing line

Cosmic inflation

This is a hypothetical moment in which the Universe became suddenly bigger. For this to have happened, space-time must have expanded at many times the speed of light. No physical laws are violated because the cosmic speed limit only applies to things that move through space-time, not to the movement of space-time. It's unclear whether inflation happened. Nevertheless, the expansion of space is making distant galaxies appear to recede from us at velocities several times that of light.

Cerenkov radiation

The optical equivalent of a sonic boom, Cerenkov radiation occurs when light passes from vacuum into a denser medium, such as water or glass, it slows down. High-energy particles travelling in the same direction often do not slow down as quickly as the light and find themselves travelling faster. They create a shock wave that pushes light out of the way. It is common to see this Cerenkov radiation as a ghostly blue glow around nuclear reactors that are covered in water.



Tachyons

This is a generic name for any particle that travels faster than the speed of light. It is a hypothetical idea that was given its present name in 1967. A particle that travelled faster than the speed of light would violate the known laws of physics unless it had some extremely peculiar properties. If such a particle were possible, it would be able to travel backwards in time, and could never slow down to travel below the speed of light. Sounds exciting, but none have ever been found.

Johnson Space Center: where scientists investigate our sci-fi fantasies

A press officer from NASA's Johnson Space Center said in a statement, "While research into theoretical faster-than-light travel from a team at the Johnson Space Center has created headlines, this is a conceptual investigation." In other words, don't pack your suitcases just yet.

Advances that could make interstellar travel possible may not just come from experiments. New extensions of gravitational theories beyond Einstein's General Relativity may show

"Travelling between stars is not going to be feasible to us for a very, very long time"

Stephen Hsu, physicist at Michigan State University

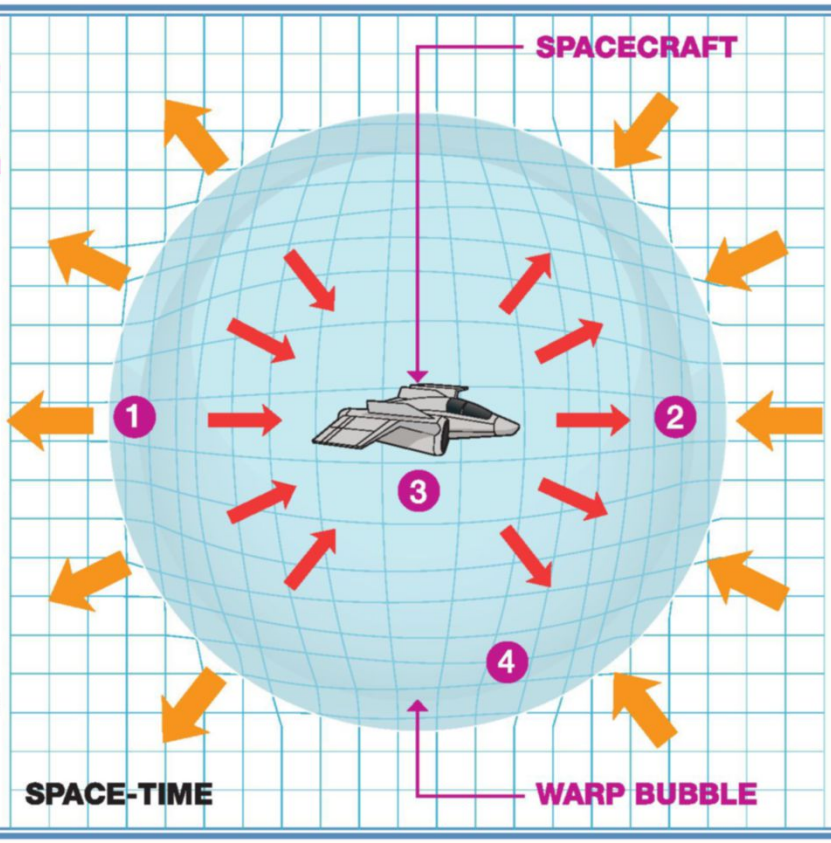
us how to break the speed of light barrier.

"According to existing theory, we should not be able to break the speed of light. But we are aware that there are limitations to the existing theory and that in reality things might

WARP DRIVE EXPLAINED

Surf through space

The theory of General Relativity makes it appear impossible for anything to travel through space faster than light-speed. But space-time itself does not suffer from such restrictions. A warp drive would be able to curve the fabric of the Universe in such a way that space-time would be contracted in front of the spacecraft, while being expanded behind it. The spacecraft would then 'surf' this movement while remaining virtually stationary in its own little patch of space-time inside the warp bubble. Pretty nifty.



1. Hypothetical negative energy would make space-time expand strongly behind the spacecraft.
2. Ordinary energy would create a powerfully contracting area of space in front of the vessel.
3. The spacecraft sits in a relatively flat region of space-time, 'surfing' the wave.
4. The depth of the warp determines the speed with which the spacecraft is carried along.

be quite different," says Portuguese physicist João Magueijo of Imperial College London.

Magueijo has been working to advance a brand new theory of gravity that applies when the force becomes extremely strong, such as near a black hole or close to the moment of the Big Bang. Both of these are places that general relativity breaks down. Magueijo hypothesises that in the moments after the Big Bang, the speed of light would be much higher than here on Earth. As well as solving a number of cosmologically puzzling observations, Magueijo has also pointed out that it could open up highways of interstellar travel.

This could be possible because many theories of the early Universe predict a phenomenon called cosmic strings. These are left over from the Big Bang and have not yet been directly observed. These 'creases' in space-time are boundaries between subtly different regions of space. They are rather like the defects that can occur in crystals. Importantly, they are massive and the speed of light would increase closer to the cosmic strings, and then stay high along its entire length.

There would be nothing to stop a spacecraft positioning itself alongside one of these cosmic strings and using it like an interstellar highway to the stars. The beauty is that you would not have to break the speed of light – you would just need some hefty engines to accelerate the craft.

Nevertheless, such exciting technology is still a long way off from becoming reality, and Magueijo remains very cautious of saying whether it's even possible. "It is clear that the theory of relativity is not the last word. But all the rest is speculation," he tells us.

And so, as Stephen Hsu confirms, we must reluctantly conclude that our dreams of interstellar travel must for now remain confined to the silver screen. "I think the classic Star Wars/Star Trek way of travelling between stars is not going to be feasible to us for a very, very long time."

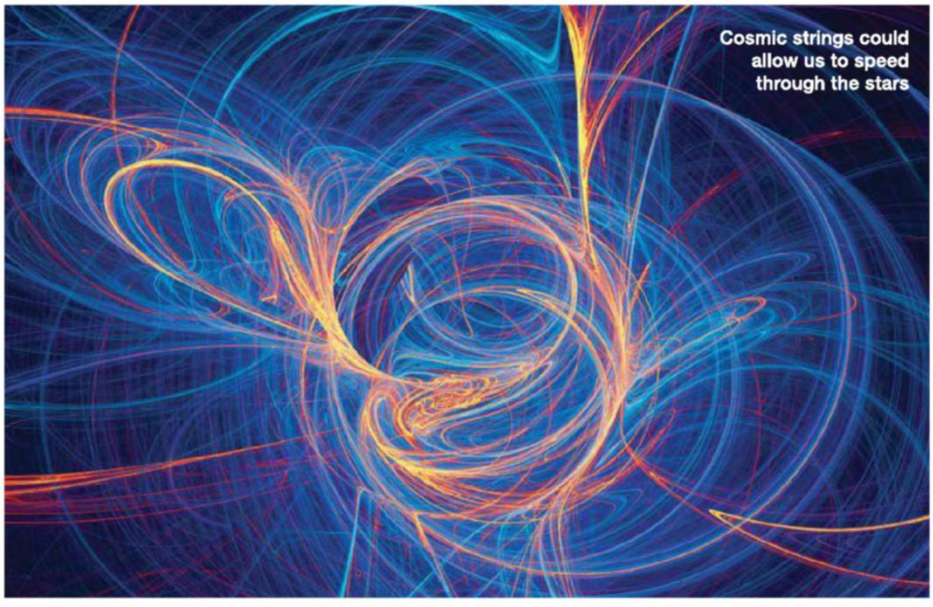

Cosmic strings could allow us to speed through the stars

PHOTO: SCIENCE PHOTO LIBRARY X4, NASA/JSC

STUART CLARK is the author of ***Is There Life on Mars? The 20 Big Universe Questions.*** **He tweets from @DrStuClark**

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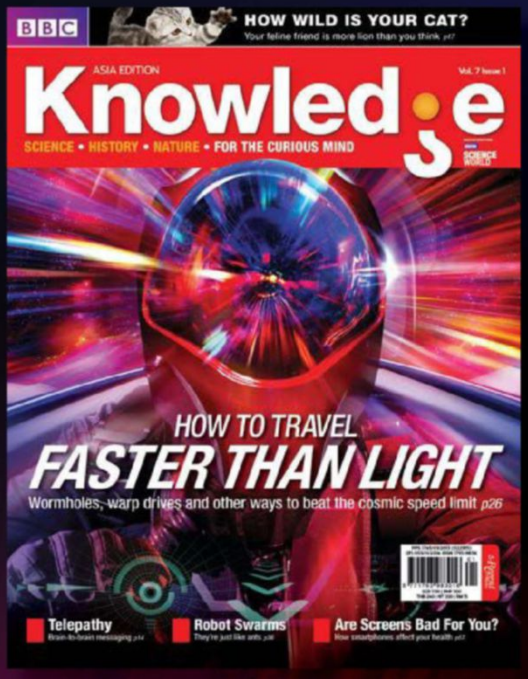

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READY, STEADY, SWARM!

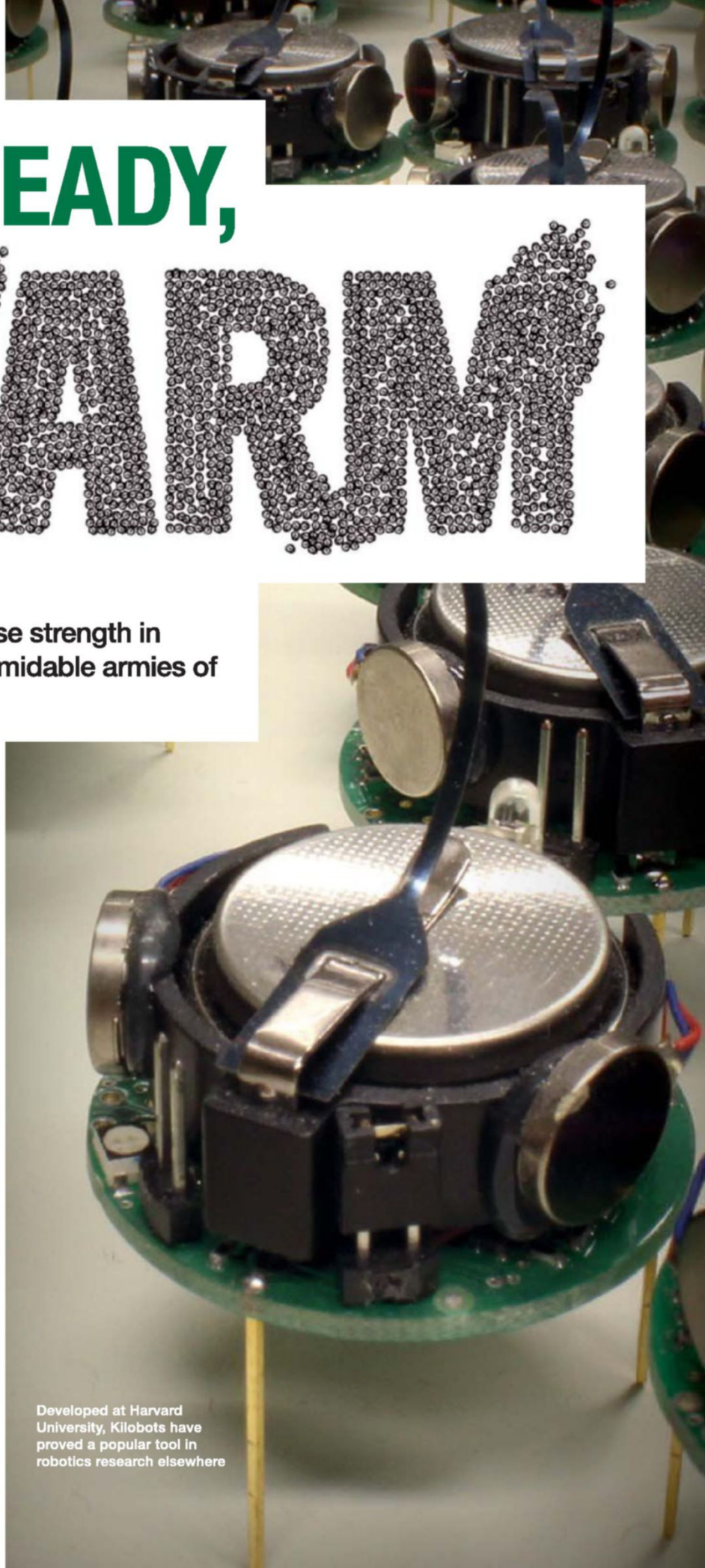
By harnessing Nature's ability to use strength in numbers, roboticists can make formidable armies of machines, reveals Emmet Cole

The natural world boasts strength in numbers. Consider the large mounds built by colonies of tiny termites, the complex anthills made by thousands of ants, or the huge ocean swarms formed by tiny krill to improve their chances when confronted by larger predators. In each of these cases, a lone individual could not complete (or possibly even survive) the task, but with hundreds and thousands of identical creatures working together, each playing their part – no matter how small that part is on its own – new capabilities start to emerge.

Roboticists have long been inspired by nature in their designs. As a result, they have given us everything from humanoid robots that look just like people, to tiny drones with the flying skills of winged insects. But can individual robots work effectively together in swarms, like so much of the natural world can?

A team of researchers at Harvard University's School of Engineering and Applied Sciences (SEAS) certainly thinks so. In August, they published a paper in the journal Science about a swarm of self-organising robots that can form different shapes on command. The swarm consists of 1,024 simple robots known as Kilobots, each costing around US$20 to make. A single Kilobot is unimpressive compared to today's advanced robots. Just 3cm across, each Kilobot moves on three spindly legs, powered by the same type of simple motor that makes your mobile phone vibrate when you get a call.

But while the Kilobot's specifications may be modest, this makes it ideally suited to the purpose of much swarm robotics research –



Developed at Harvard University, Kilobots have proved a popular tool in robotics research elsewhere

PHOTO: MICHAEL RUBENSTEIN

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WHAT IS SWARM ROBOTICS?

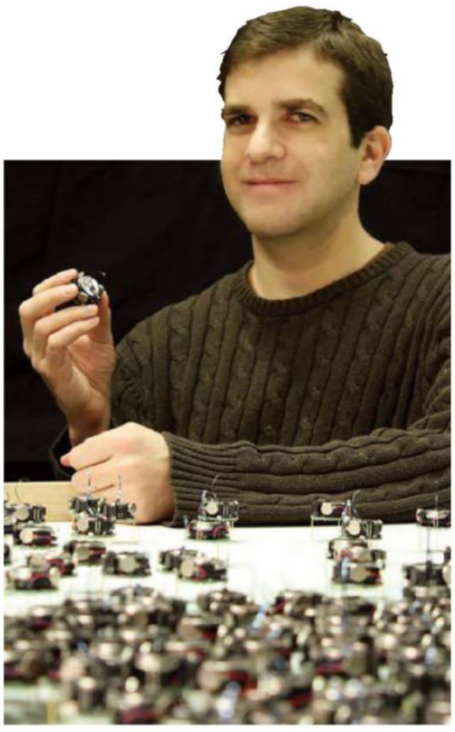
The term swarm robotics' is used to refer to multi-robot systems of different types and sizes – from small shape-shifting Kilobots to larger Swarm-bots that can pick up and move objects around. Individual robots in swarms are generally quite uncomplicated in design and follow simple rules, and the control of robot swarms is decentralised, which means control of the swarm is not dependent on a single member. Inspired by the swarm intelligence displayed by insects such as ants and bees, swarm robotics builds on computer models of this behaviour developed in the 1990s by Marco Dorigo and others.

So why are roboticists interested in robot swarms? One of the most important benefits is that swarms are more fault-tolerant than a single robot. If an individual robot in a swarm fails, the others will continue working. In some cases, robots in the swarm can even compensate for and correct the errors of a single member. And since there is no 'leader', there is no single point of failure that could cause the whole swarm to fail.

Additionally, robot swarms are scalable, which means robots can be added and removed without new code being required. Robots in a swarm also tend to work in parallel, carrying out several tasks at the same time. Finally, research robots are complicated to design, build and maintain, which makes them expensive. A swarm of simpler robots can provide the same functionality at a significantly reduced cost. Still a relatively new field, swarm robotics is set to grow rapidly in the coming years as electrical components become both smaller and cheaper.

A swarm of robots can form predetermined shapes like the starfish shown above

PHOTO: ELIZA GRINNEL/HARVARD SCHOOL OF ENGINEERING AND APPLIED SCIENCES, M SCOTT BRAUER, MARCO DORIGO/IRIDIA/UNIVERSITÉ LIBRE DE BRUXELLES, MICHAEL RUBENSTEIN X6



Harvard fellow and Kilobot creator Mike Rubenstein shows off a swarm of his miniature creations

"Keep it cheap and simple and build a swarm that's capable of doing interesting things"

Mike Rubenstein of Harvard University on the primary aims of the Kilobot project

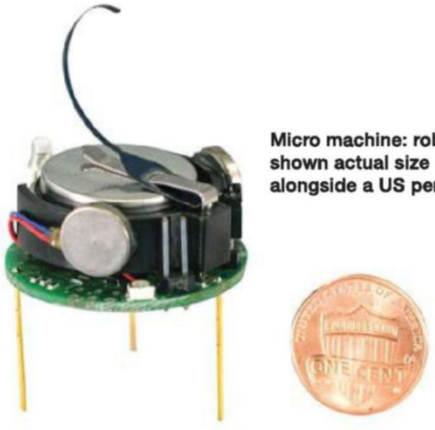
exploring the ways in which simple robots can combine to perform complex tasks they could not perform alone. To get the swarm to form a shape, researchers upload a 2D image of the desired shape to each robot. Special 'seed robots' placed by scientists mark the position and orientation of the shape and remain in position throughout the entire process. An overhanging infrared light sends a single instruction to the assembled swarm, 'Go!'. At that point, each robot uses information from the robots surrounding it to work out approximately how far it is from the seed bot. Those that are farthest away start moving along the edge of the swarm. Once they reach the seed bot, robots can work out their precise position – and communicate that information to other robots within a 10cm radius using tiny infrared sensors. The robots stop moving when two of three conditions have been met: they find themselves within the area designated for the shape, and they have either reached a boundary or touched a robot that has stopped in front of them. Using just these simple rules, the robots form the desired shape. Further, if one of the robots makes a mistake, the algorithm devised by Rubenstein and his colleagues allows the rest of the swarm to correct it.

The swarm is not quick by any means. Shape formation can take anywhere from 6 to 12 hours. But this is the largest swarm of its type ever studied, and future models are certain to be faster. That ant colony wasn't built in a day. The biggest challenge for the Kilobot researchers was building a robot that's cheap enough to manufacture by the thousand, but also capable enough to perform worthwhile behaviours, says first author on the Science paper, Mike Rubenstein, a post-doctoral fellow at Harvard.

"Those are conflicting abilities – to keep it cheap and simple and to build a robot swarm that's capable of doing interesting things without being complicated."

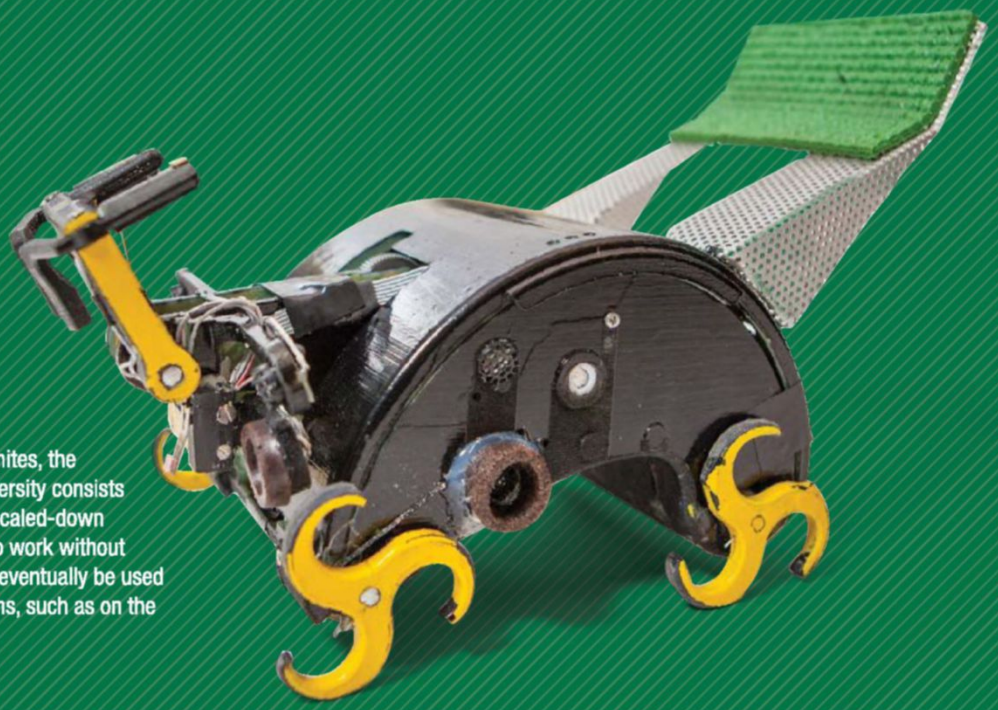
Kilobots are a great tool for researchers, says Marco Dorigo, one of the world's leading experts on swarm robotics and co-director of IRIDIA, the artificial intelligence lab of the Free University of Brussels, Belgium, who was not involved in the Kilobot project. "We have 120 Kilobots in our lab and use them in our research. They are very simple robots and very cheap, which makes them feasible for researchers with a limited budget. They are also small, which means that you don't need much space for experiments. It was a very good idea to release them."

Robot swarms are ideally suited to tasks that are dangerous, and tasks that call for robots to be distributed over a wide area, says Dorigo. "When the task is dangerous for the robot, you will be glad the system is fault-tolerant. If they break down, the system will show some degradation in the performance but it will still work. And if your task requires you to be in many places at the same time, the swarm is



Micro machine: robot shown actual size alongside a US penny

MORE ROBOT SWARMS



1 Termes

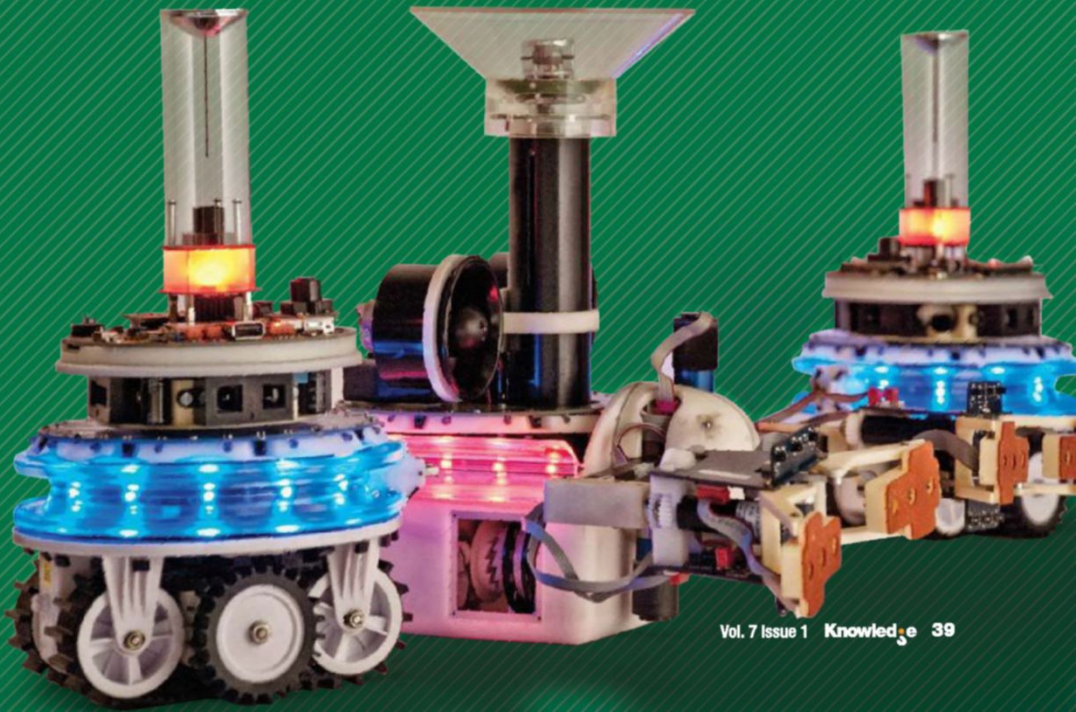
Inspired by the mound-building behaviour of termites, the TERMES robot swarm developed at Harvard University consists of autonomous climbing robots that can build simple, scaled-down architectural structures. The TERMES swarm's ability to work without human supervision means that a similar system could eventually be used for construction work in remote and dangerous locations, such as on the Moon or other planets.

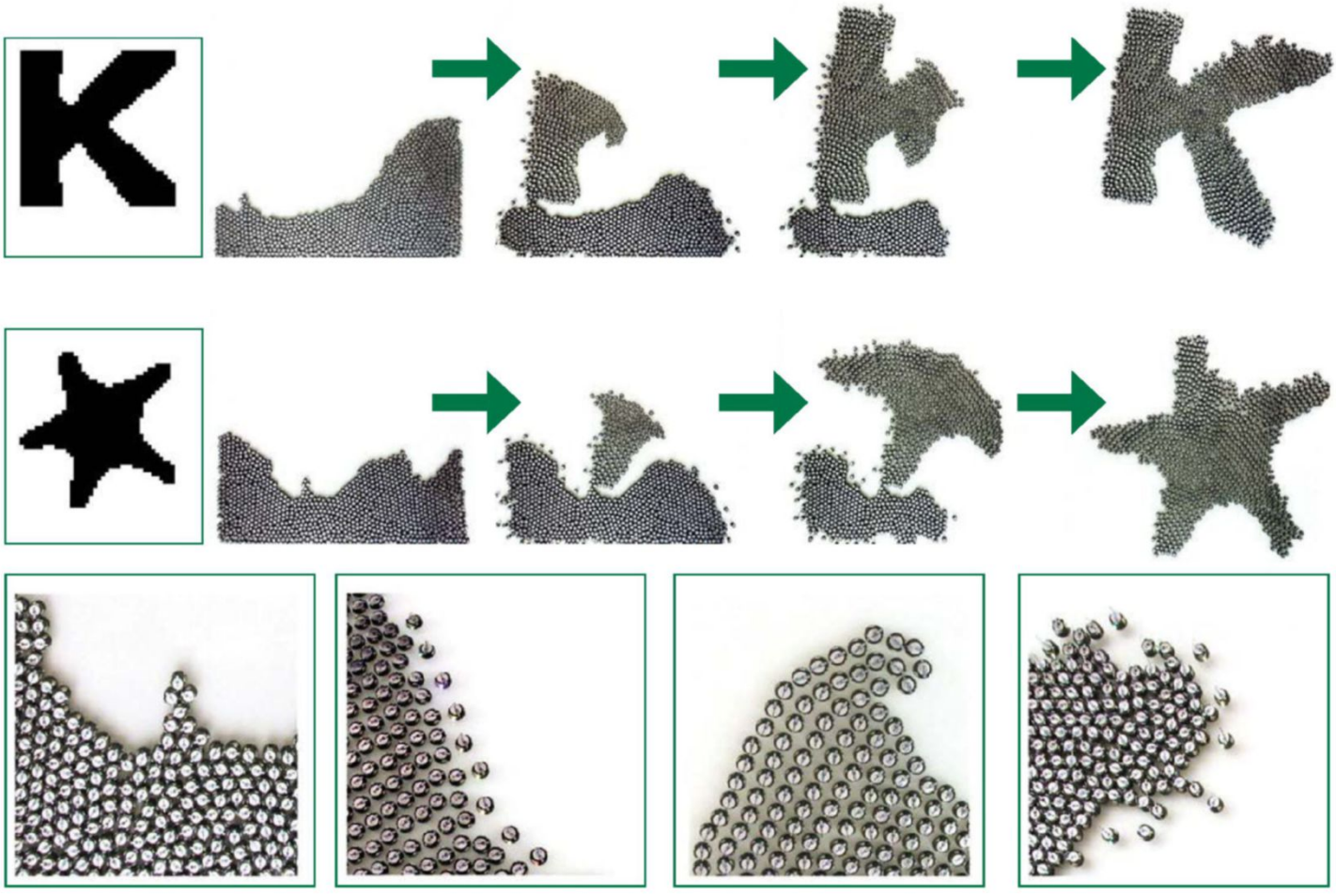
2 Robot Pebbles

Swarm robotics meets programmable matter in the Robot Pebbles project from Massachusetts Institute of Technology. Each cube-shaped robot is just 12mm per side and weighs only 4.0g, but houses a powerful magnet that allows groups of the robots to connect and form complex shapes. The team is currently working on ways to further miniaturise the robots, with the aim of creating what they call 'Smart Sand' – a programmable matter system consisting of intelligent robotic cubes, each measuring just 1mm on each side.

3 Swarmanoid

This is a 60-strong swarm of small, autonomous robots developed by Marco Dorigo's team at Free University of Brussels, Belgium. The swarm consists of three types of robot: foot-bots, hand-bots and eye-bots that can collaborate and combine their different skills to complete specific tasks. Lessons from the Swarmanoid project are being explored in Dorigo's current project, the European Research Council-funded e-Swarm, which is looking at ways to model the behaviour of individual robots within large swarms.





Top: How the robots arranged themselves to form the black 'K' and starfish shapes
Above: Close-up view showing the individual robots in action. They're quite slow – the 'starfish' took nearly 12 hours to self-assemble

better than having a single robot."

Likely applications for swarm robots include search and rescue missions and pollution containment, says Dorigo. Habitat construction – on Mars, for example – is another possibility, but for Dorigo it's still too early to say how swarms will end up being used. "It's very difficult to predict because at the moment we are quite far from real-world applications. This is more because of the limitations of the single robot, rather than because of a limitation of the swarm. The individual robots are still too brittle and cannot do much," explains Dorigo.

Better together

But can the intelligence of a robot swarm be greater than the sum of its parts? If you measure intelligence in terms of overall functionality, then the answer is yes: a swarm can perform more jobs than a single robot. However, there is no magical extra intelligence that emerges from a robot swarm that cannot be explained in terms of the capabilities of its individual members, explains Dorigo.

"We're quite far from real-world applications. The individual robots cannot do much"

Marco Dorigo of the Free University of Brussels on the current limitations of swarm robotics

Emergent (or unexpected) behaviours in robot swarms tend to be the result of mechanical and programming errors and lack of foresight on the researchers' part, rather than any mystical property of the swarm.

In future, however, the intelligence of a robot swarm might exceed the sum of its parts, says Rubenstein. "That's the hope. We're starting to be able to get towards something like that, where not only can they be more intelligent but where they can, for example, see things as a swarm that they could not see by themselves."

Long-term, he's interested in "the futuristic idea" of building objects using swarms of tiny robots. This is where swarm robotics meets 'programmable matter' – matter that can be programmed to change its physical properties.

"The idea is to try to work towards the goal where you could construct tools or other robots made of thousands of little tiny robots. You can build a tool that can adapt to its environment better or recover from errors faster if made of lots of little robots," says Rubenstein. Along with his colleagues, he is now planning to explore algorithms that can form shapes more reliably and faster. After that, they want to investigate how a swarm could form shapes without any human instructions, by working out the optimal shape for the task at hand by itself. "The algorithm that we released in the *Science* paper was the first that we have done on the full thousand robots. But hopefully it won't be the last one," says Rubenstein.

EMMET COLE is a technology journalist and a columnist for *Robotics Business Review*

PHOTO: MICHAEL RUBENSTEIN

DRESSED FOR SUCCESS

The discovery of more than 40 species of feathered dinosaurs has revealed some remarkable details about the evolution of feathers and flight, reveals John Pickrell

One hundred and twenty million years ago, in the part of the world we now know as northeastern China, strange creatures shared the swampy forests with early birds and large ground-dwelling dinosaurs. In the dusky light, as the Sun starts to dip below the horizon and nocturnal insects hum to life, an animal the size of an eagle spreads its wings and leaps from a high branch. It's covered in thick grey plumage and at first glance appears to be a bird – but several features pick it out as something else entirely. Incredibly, it has four wings – feathered hindlimbs as well as forelimbs – and a long tail replete with flight feathers, which it spreads out to provide the largest possible surface area for gliding.

Changyuraptor yangi – described in Nature Communications in July – is the largest of a growing group of known feathered dinosaurs that could glide. Its long tail was tipped by 30cm feathers, which may have helped this hefty 4kg flyer control its speed of descent.

The discovery of feathered dinosaurs, such as Changyuraptor, are coming thick

A fossil of *Changyuraptor yangi* (artist's impression above) with remarkable detail of its plumage

PHOTO: L CHIAPPE/DINOSAUR INSTITUTE/NHM

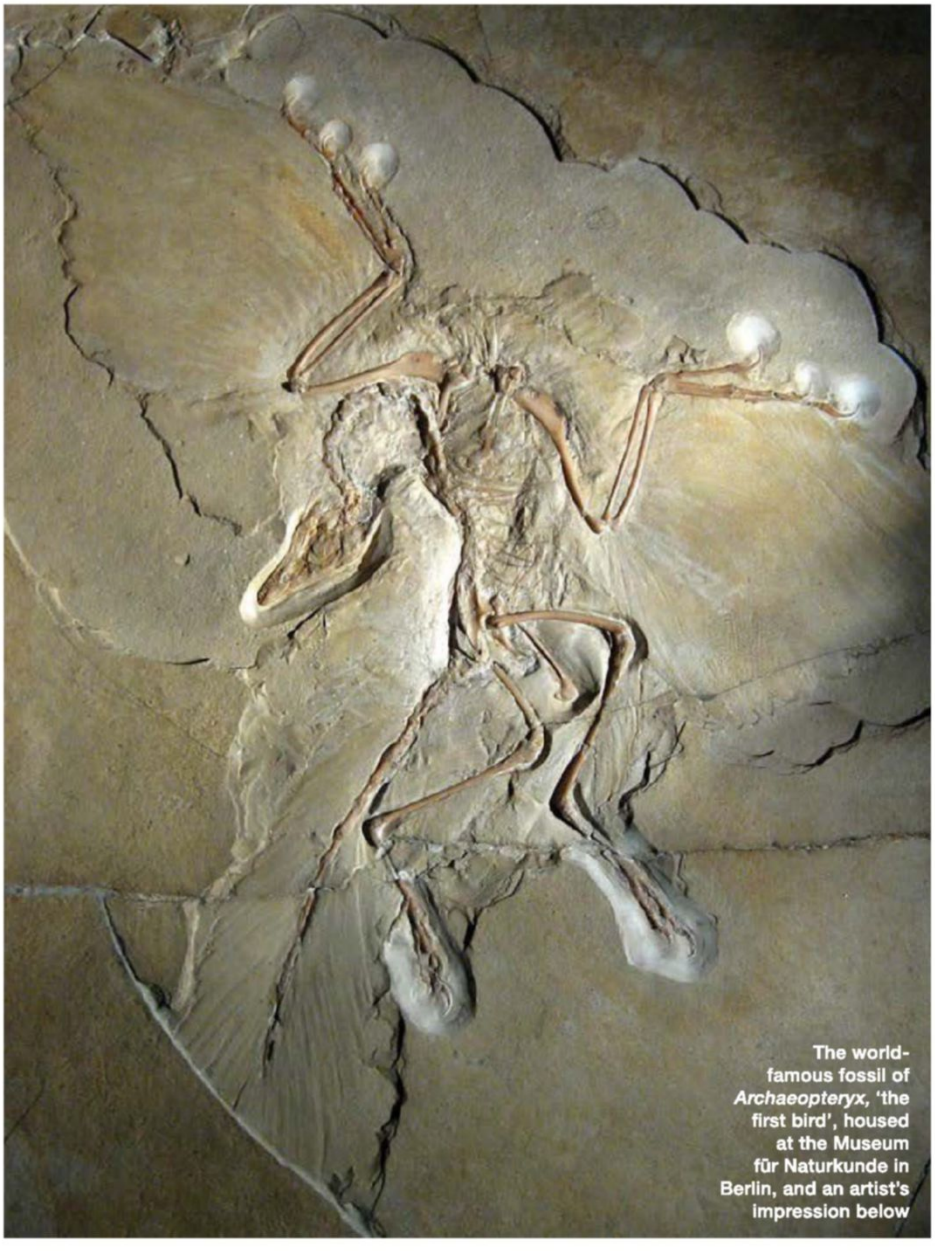
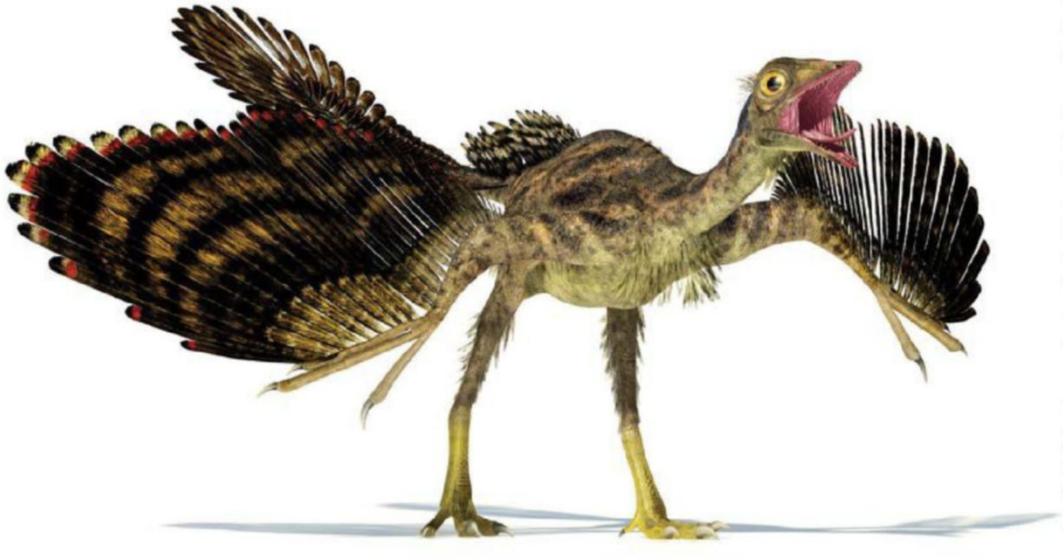


PHOTO: H RABB/WIKI, AMNH/D FINNIN, GETTY, SCIENCE PHOTO LIBRARY

The world-famous fossil of *Archaeopteryx*, 'the first bird', housed at the Museum für Naturkunde in Berlin, and an artist's impression below



and fast these days. Others announced to the world in 2014 include the small Siberian herbivore Kulindadromeus zabaikalicus, and Anzu wyliei – labelled a 'cross between an emu and a lizard' by its discoverers and only the second feathered dinosaur known from North America. More recent finds have included a new fossil specimen of the 'first bird' Archaeopteryx, and a study which showed how dinosaurs shrank 12-fold over a period of 50 million years in the lineage that led to modern birds.

There is now good evidence that many carnivorous dinosaurs, even fearsome and well-known types – such as Allosaurus, Velociraptor and Tyrannosaurus – had feathers, and that they used them for a variety of functions. Feathers are so intimately entwined in our

"The creature retained traces of four, long, ribbon-like feathers, which it could have flicked to woo mates"

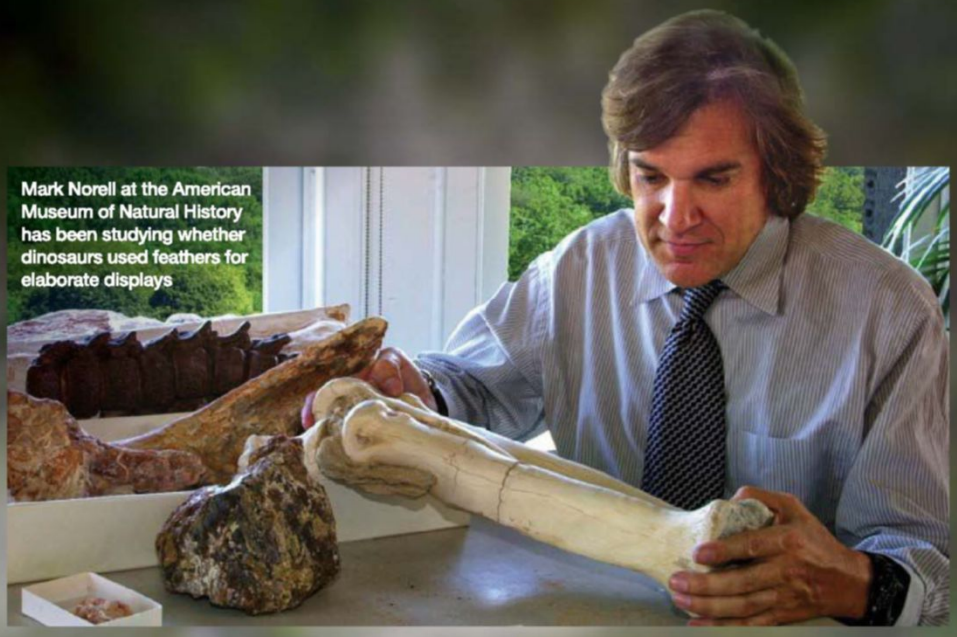
minds with flight that this idea takes some getting used to. Nevertheless, complex flight feathers can't have appeared from nowhere, so it makes sense that the earliest feathers had another purpose entirely.

Since the discovery of the first feathered dinosaur, Sinosauropteryx in 1996, a great flock of 40 or so feathered species has flapped or scurried to the fore. These fossilised creatures have been found with feather impressions, or with circumstantial evidence in the form of either 'quill knobs' (pits in the bones where the ligaments of feathers attach) or a 'pygostyle' (the bony tail structure to which a fan of feathers attaches in birds).

Nearly all of these species are carnivorous theropods, and the majority are exceptionally preserved specimens from Liaoning Province in northeastern China, although some hail from Mongolia, Germany, North America and Madagascar. In the years following the

discovery of Sinosauropteryx, it became clear that most wouldn't have been able to fly – they didn't have fully formed wings or they weren't the right kind of shape. Palaeontologists began to realise that feathers evolved for another purpose entirely and were only later co-opted for flight.

The feathers of many of these animals were simpler in structure than anything we'd recognise as feathers today, and it's likely they were used like the downy fuzz of chicks for insulation. "To start with, feather structures are not all that complicated – they are a coat of simple filaments," says Dr Paul Barrett, a palaeontologist at the Natural History Museum in London. "These animals are small and quite active, they have elevated metabolic rates… and this is a way of retaining heat."



Mark Norell at the American Museum of Natural History has been studying whether dinosaurs used feathers for elaborate displays

Dino displays

After feathers first found a use in insulation, they developed another purpose. In 2007, in Inner Mongolia, Chinese Academy of Science experts unearthed the finely preserved fossil of a bird-of-paradise-sized dinosaur, which they called Epidexipteryx, Greek for 'display feather'. These scientists noted in a 2008 Nature article: 'Ornamental plumage is used to send signals essential to a wide range of avian behaviour patterns, particularly relating to courtship… It is highly probable that the [tail feathers] of Epidexipteryx similarly had display as their primary function.'

The fossilised creature retained traces of four, long, ribbon-like feathers, which it could have flicked and wafted as it danced to woo mates, as birds of paradise do today. This weird dinosaur was a compelling piece of evidence that early feathers were used for display too.

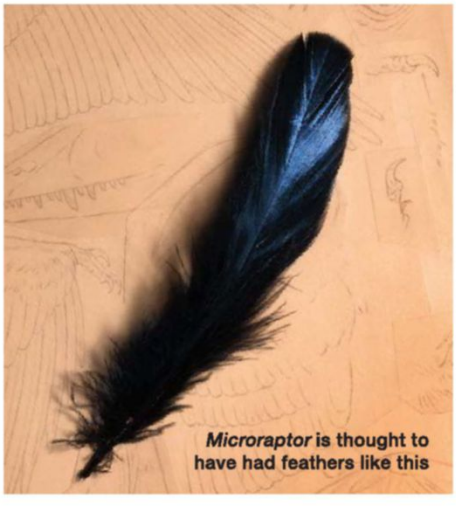
Other groups of dinosaurs had big 'pennaceous' feathers (the typical modern shape, with a central vane and interlocking barbs running off to either side) on their forearms and tails, which were more obviously used for showing off.

A 2013 study by experts including Phil Currie and Scott Persons at the University of Alberta, and Mark Norell at the American Museum of Natural History,

Fossils of *Epidexipteryx* show that it may have used its feathers as a display to attract mates

Recent studies have shown that the four-winged *Microraptor* had iridescent plumage

"Until recently, the consensus was that *T. rex* and other large theropods probably only had feathers as juveniles, if at all"



Microraptor is thought to have had feathers like this

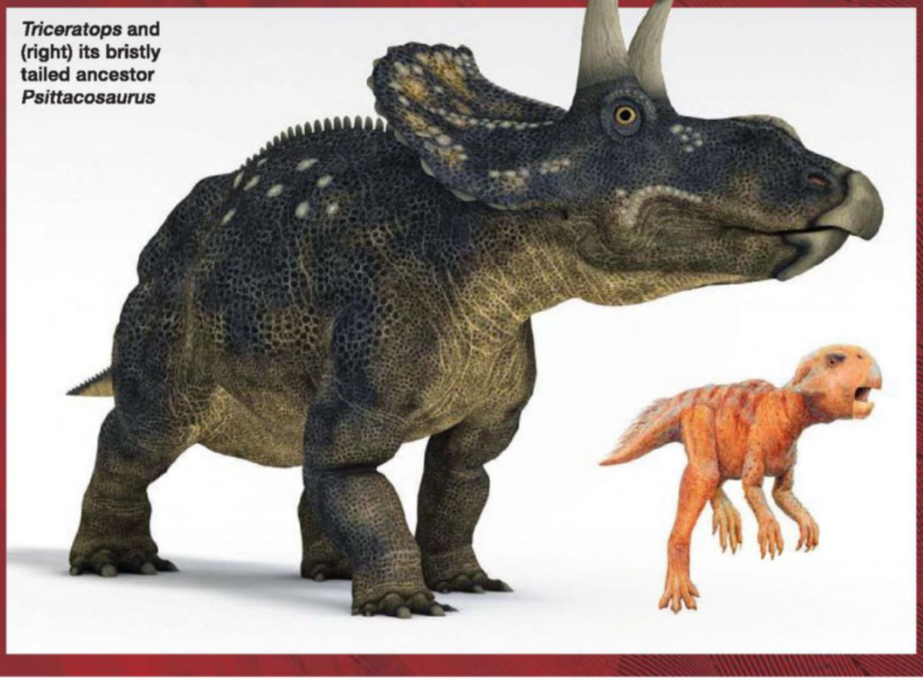
provides perhaps the best evidence yet that dinosaurs used feathers for elaborate displays. Oviraptorids are parrot-beaked omnivorous theropods, that had a 'pygostyle' tail, where the final few vertebrae are fused to form a ridged, blade-like structure. The researchers found marks on the bones of five different species of oviraptorids, which suggested large muscles that would have allowed the stumpy tail to be flexed and posed in a number of ways. The conclusion was that male oviraptorids likely indulged in tail-shaking mating displays, much as turkeys and peacocks do today.

So there's good evidence of early feathers being used for insulation and display, but how did they come to find a function in flight? Eventually, the extra surface area of feathers on the tail and forearms used for display would have offered some lift when jumping or gliding. Then evolution would have started to select for the running or flying functions of feathers, eventually leading to four-winged dinosaurs such as Changyuraptor and Microraptor that lived in the trees.

Most known feathered dinosaurs are close relatives of birds in the carnivorous theropod group of dinosaurs. Although feathers are only known from a smattering of species across the whole group, the fact that some are early and primitive members and that feathered species are found on many different branches of the family tree, suggests that all theropods were feathered.

DID TRICERATOPS HAVE FEATHERS?

It's often portrayed with a thick, scaly hide, but the beast may have been covered in bristles



Triceratops and (right) its bristly tailed ancestor *Psittacosaurus*

There are some hints that 8m-long, crested herbivore *Triceratops* may have had a bristly covering related to feathers. *Psittacosaurus* is a 1.5m-long, Early Cretaceous member of the parrot-beaked ceratopsian lineage that eventually led to *Triceratops*. Some *Psittacosaurus* specimens discovered in China have revealed plumes of bristles around the tail.

The only skin-impression fossil found for *Triceratops* (which lived in North America near the end of the dinosaur era in the Late Cretaceous) appears to reveal it had bristles, not purely scaly skin as has been long supposed. The remarkable fossil was found by palaeontologist Dr Bob Bakker and is held at the Houston Museum of Natural Sciences in Texas, where he is a curator. We know that *Psittacosaurus* had bristles, so given it is an early member of the lineage that led to *Triceratops*, it seems reasonable to assume that these were passed down.

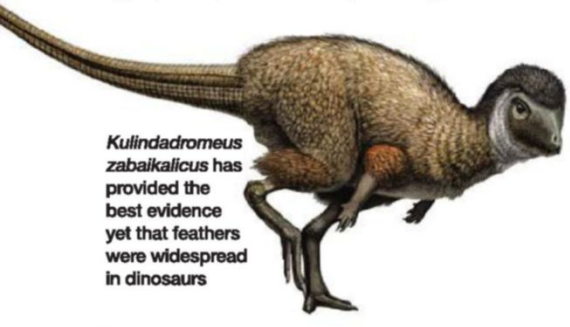
PHOTO: JASON BROUGHAM, GETTY, SCIENCE PHOTO LIBRARY, ANDREY ATUCHIN, MICK ELLISON

Despite this, until recently, the consensus was that T. rex and other large theropods probably only had feathers as juveniles, if at all. The idea was that huge animals don't need insulation, as they lose heat to the environment very slowly. But the discovery of a series of feathered relatives of Tyrannosaurus has turned this idea on its head. The first, Dilong paradoxus, was discovered by legendary dinosaur hunter Professor Xing Xu in Liaoning in 2004. As this lightly built, 125-million-year-old predator was relatively small, at 2m in length, its downy covering was not wholly unexpected.

Much more surprising, though, was 9m Yutyrannus huali discovered in 2012. Also from the Early Cretaceous deposits of Liaoning, this shaggy predator was closer in size to T. rex itself. It showed that downy feathers were probably much more widespread among dinosaurs than anyone had expected. Yutyrannus is the largest feathered animal ever known to have lived.

A few of the new fossils, however, hint that feathers might have originated much deeper in the dinosaur family tree, not close to the ancestors of modern birds. For example, Tianyulong confuciusi was a small bipedal herbivore with a fuzzy covering of fluff. Nothing unusual in that, except it's in the ornithischian group of herbivorous dinosaurs, which are very distant cousins to the carnivorous theropods. Another ornithischian – Psittacosaurus, a small and early relative of Triceratops – also had bristle-like structures, which may have been a form of feather.

The new Siberian species, Kulindadromeus zabaikalicus, described in July, is the best evidence so far that feathers may have been very widespread across all dinosaur groups. This 1.5m-long ornithischian herbivore may have had three different types of feathery filament, as well as scales on different parts of its body.



Kulindadromeus zabaikalicus has provided the best evidence yet that feathers were widespread in dinosaurs

Flying reptiles

There's even the tantalising possibility that feathers originated in the ancestors of animals that gave rise to dinosaurs and their sister group of flying reptiles, the pterosaurs. "Even the filaments of pterosaurs are likely to be a kind of primitive feather," argues Xu, a world expert on feathered dinosaurs at the Institute for Vertebrate

Known types of dinosaur feather

Sinosauropteryx | Caudipteryx | Anchiornis | Archaeopteryx | Confuciusornis

Early birds (*Longirostravis*) perch on one of their large dinosaur relatives (*Yutyrannus*); both species lived in the Cretaceous period

PREHISTORIC PALETTE

Once a mystery, the power of science is starting to reveal the remarkable colours of dinosaurs

As recently as five years ago, experts thought we'd never be able to tell anything about the colour of dinosaurs. Most were painted in greens and browns similar to lizards and crocodiles. Since the discovery of feathered dinosaurs in 1996, the assumption had been that they might have had some of the same variation in plumage that birds do, but few believed this would ever be confirmed. That was until January 2010, when a study led by Professor Mike Benton at the University of Bristol suggested that *Sinosauropteryx* – the first feathered dinosaur discovered – had ginger and white stripes around its tail, something like a ring-tailed lemur. Similar work has now revealed the true colours of *Archaeopteryx* and four-winged flyers *Anchiornis* and *Microraptor*.

Tiny clues as to the colour of the feathers was found in the structural details of the well preserved fossils of some dinosaurs and early birds. In hair and feathers there are miniscule pigment packages called melanosomes. The way these are stacked or bunched, and whether they are round or oblong, correlates to some of the colours. This has given experts clues as to whether the feathers in fossils were black, brown or red, for example. Iridescent colour is also created by structural features and we can find these in fossil feathers too.

PHOTO: DAVIDE BONNADONNA, SCIENCE PHOTO LIBRARY

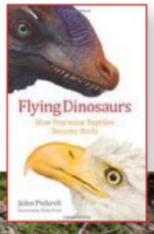
The striking ginger and white striped tail of *Sinosauropteryx*

Palaeontology in Beijing. Experts have known for some years that many pterosaurs had a fur-like covering, which perhaps helped them maintain a high metabolic rate for flight, but it's not yet clear if this is related to feathers or evolved independently.

Others aren't so sure that feathers were common across all dinosaur groups. There's no evidence of feathers in most other ornithischians, according to a 2013 study by Paul Barrett of the Natural History Museum and David Evans of the Royal Ontario Museum. "We have lots of skin impressions from duck-billed and horned dinosaurs, and none of them show anything that looks like feathers," says Barrett. This could be because the ancestors of these dinosaurs started off with feathers and lost them, or it could just be that dinosaurs have within their genes the mechanism to easily evolve skin-related structures, he says. "They also have lots of armour and spikes that form in the skin too." It could explain why some groups have feathers, frills or armour and others don't.

The question now is did all dinosaurs and pterosaurs inherit feathers from the same common ancestor, or is it just that the group had a remarkable plasticity to play around with different structures like bristles, quills, fuzz, fluff, ribbons and, eventually, complex and beautiful feathers sculpted for the purpose of flight? Research is ongoing, so hopefully we'll soon know more about these incredible creatures.

JOHN PICKRELL is the author of *Flying Dinosaurs: How Fearsome Reptiles Became Birds*



6 REASONS YOUR CAT IS WILDER THAN YOU THINK

That purring ball of fluff sitting innocuously on your lap can never be truly tamed. John Bradshaw investigates the evolutionary quirks behind one of the world's favourite pets

Pet cats may be domestic animals, but they're not fully domesticated. The cat family – felids – separated off from the other carnivora about 11 million years ago, and apart from size, have not altered a great deal since then, such that even today they are all obviously cat-like. Domestic cats still have much in common with their wild cousins, from the noble lion down to the tiny (and very rare) kodkod, found in Chile. Turn over to find out just how similar your tabby is to a tiger.

1 Your cat loves meat

Millions of years ago, a dozen or so genetic changes took place in the ancestor of all of today's felids, which have locked them into eating meat ever since. All cats, from tabby to tiger, require high levels of animal protein in their diet – protein from plants lacks certan amino acids, such as taurine, that cats need but other mammals (including ourselves) do not.

Cats can't make their own prostaglandins – hormones essential to reproduction – and so need to get these from meat. Compared to other mammals, all cats need large amounts of several vitamins, such as niacin, thiamine and retinol, which are more easily extracted from meat than from plants. And because they don't need to tell the difference between ripe and unripe fruit, they've lost the ability to taste sugars. They have adapted their 'sweet' taste buds for distinguishing between different flavours in meat – which is why pet cats sometimes walk away from food that seems fine to their owners.

This knowledge has only come to light in the past 40 years, benefiting not only pet cats but also the captive breeding of endangered felids such as the clouded leopard. As many of two-thirds of all felid species are endangered.

> "The domestic cat is the only felid species in which males are solitary and females are sociable"

2 Only 15-20 genes separate your cat from wildcats

The domestic cat's DNA was first sequenced in 2007. This has since been repeated for the European wildcat, *Felis silvestris silvestris*, which is first cousin to the domestic cat's ancestor, the Arabian wildcat *Felis silvestris lybica*. The European and Arabian wildcats separated about 200,000 years ago, whereas it has only been 10,000 years since the domestic cat *Felis silvestris catus* emerged as a distinct subspecies. Once the first Arabian wildcat is sequenced, we should be able to pinpoint the crucial differences that make it possible for domestic cats to socialise with us, something wildcats find impossible.

3 Domestic cats (and lions) are the only social felids

Most cats lead solitary lives, kept apart by the need to monopolise a hunting area. The lion is the only species in which males and females live together in prides, which they can do because they hunt prey that is large enough to feed many lions, not just one. Female cheetahs are solitary, but males sometimes live as a group. The domestic cat is the only felid species in which males are solitary and females are sociable: mothers and daughters often raise their kittens together. Pet cats show affection for us as they do with other cats – raising their tails upright and attempting to groom us – so perhaps they perceive people as just large, two-legged felids.

PHOTO: GETTY, THINKSTOCK X2, ALAMY, FLPA

4 Your cat's huge eyes indicate its predatory tendencies

Of all felids, only the cheetah specialises in hunting by day, and so has fairly small eyes. Many of the larger cats have slightly larger eyes that are more sensitive than ours, allowing them to hunt by moonlight as well as during the day. But most of the smaller species, including the domestic cat, are mainly nocturnal in the wild. So that they can gather enough light to see by, their eyes are huge relative to their skulls – a domestic cat's eyes are almost as big as ours. Inside the eye, the retina is about six times as sensitive as ours, and wired to the brain in such a way as to maximise sensitivity, at the expense of sharpness. All felids also possess a reflective layer behind the retina, the tapetum, that further increases sensitivity while at the same time producing their distinctive green 'eye-shine' when caught in a torch-beam.

5 When your cat's playing with a toy, it thinks it's hunting

Cats were originally domesticated to keep mice and rats away from our farms, homes and grain stores, and although nowadays we don't generally encourage our pet cats to do this, inside their heads they're still hunters.

The way they 'play' demonstrates this fact perfectly. When they're playing with small toys, they use the same techniques they use on mice, such as pouncing, and grasping in the mouth. Larger toys, however, are attacked not with the teeth but with all four sets of claws – reflecting the need to hold a rat, which can be a formidable foe, at arms' length.

Even more revealing is the effect of hunger on play: a pet cat that hasn't eaten overnight plays much more intensely than when it's just had breakfast, as if it believes that ripping apart a felt mouse will actually produce a meal.

JOHN BRADSHAW is a BBC TV presenter and the author of *Cat Sense: The Feline Enigma Revealed*.

6 Your cat has two noses

Predators rarely live in close proximity, and see or hear each other only rarely, so they have to communicate by smell. Lions, tigers and domestic cats deposit urine around their territories, and they also rub their cheeks on prominent landmarks, leaving behind scent from their skin glands. All cats also possess a second 'nose' – Jacobson's organ – purely for analysing the smell of other cats. This lies between the nostrils and the roof of the mouth. The outward sign that it's being brought into play in lions and tigers is a curling of the top lip, a posture referred to as 'Flehmen'. Domestic cats instead they look as though they're going into a brief trance. Muscles around the Jacobson's organ pump a drop of fluid into the mouth, where it dissolves some of the odour being sampled, before being drawn back up into the organ for analysis.

THE STRUCTURE OF HUMAN CELLS

BY KATHERINE NIGHTINGALE

The invention of the microscope kick-started a scientific journey of discovery into the world of the very small that culminated in our understanding of the building blocks of the human body

When people think of scientists, they often think of people in white coats peering down microscopes. That's no surprise – the microscope has been instrumental to finding out what's inside us. The first microscope came from the Dutch city of Middelburg around 1590. This was a time of great interest in the power of lenses, whether for spectacles, magnifying glasses, telescopes or microscopes. Some would use these new technologies to gaze into the heavens. Others peered inwards, instead staring into the 'microcosmos', the world of the cells inside us.

During the 1600s, scientists began to study all kinds of materials under their microscopes. Not least of these was Robert Hooke, who in 1661 was passed a royal commission to study insects. Hooke set about designing a new type of microscope for the job. With its three lenses, it magnified objects by 50 times.

He studied insects and materials, producing brilliant technical drawings for his Micrographia book, published in 1665. Micrographia also holds Hooke's most significant contribution to cell biology. When peering down his microscope at a thin sheet of cork, he saw what appeared to be many empty spaces bound by wall-like structures. Reminded of the small rooms in which monks dwell, he named them 'cells'.

Perhaps drawn to microscopy after seeing Hooke's studies of fabrics, Dutch tradesman Antonie van Leeuwenhoek became adept at grinding lenses, making them with such precision that he could magnify objects to 270 times their size. His microscopes used just a single, tiny spherical lens, and gave him unprecedented access to the hidden world.

A louse clinging to a human hair is one of the remarkable images that features in Robert Hooke's *Micrographia*

In 1675 he found single-celled lifeforms – now called protozoans – in drops of rainwater, and in 1683 he studied his own tooth scrapings and found bacteria, tiny moving beasts he named animalcules ('little animals').

Cells are generally transparent, making it difficult to discern their contents, even with improved microscopes. Van Leeuwenhoek is the first thought to have used cell 'stains', adding saffron to muscle cells to increase the contrast between cell components. Together Hooke and van Leeuwenhoek are credited with discovering cells, a feat which would have been impossible without their microscopes.

The life within

Humanity had found cells, but what were they? It was the discovery of their first component that would bring about a deeper understanding of

PHOTO: SCIENCE & SOCIETY, SCIENCE PHOTO LIBRARY

This artist's impression of a human cell shows organelles surrounded by cytoplasm and a membrane

> IN A NUTSHELL

Harnessing the power of microscopes enabled scientists to explore a world invisible to the naked eye and discover that plants and animals are comprised of cells. Technological advances then meant we could learn how cells work.

their role, and what Hooke's dead cork cells had in common with van Leeuwenhoek's little animals.

Even though many others must have spotted it, it was the Scottish botanist Robert Brown who first named and described the cell nucleus – the control centre – in orchid cells in 1831. We now know that the nucleus contains the chromosomes of DNA and is the seat of power from which our genes regulate the rest of the cell.

A few years after Brown named the nucleus, in 1837, the German scientist Theodor Schwann was having lunch with a fellow German researcher, the botanist Matthias Schleiden. Their conversation turned to the nucleus, which had so far been seen only in plants. Schleiden had observed that new plant cells seemed to come somehow from an existing nucleus. Schwann, who had been studying animal cells, remembered seeing structures that could well be nuclei.

Excited, the pair rushed to Schwann's laboratory to look at tadpole tissue. There were the nuclei: animals must be made of cells too. Both scientists wrote up their findings, with Schleiden describing cells as the 'building blocks of life', and Schwann stating: "All living things are composed of cells and cell products." It may seem obvious now, but this 'cell theory' was revolutionary: all life from algae to aardvarks, bacteria to begonias, was made of cells.

The subsequent decades of the 19th Century, as microscopes improved, were fertile times for discovering the components of cells, and teasing apart the differences between the cells of animals, plants and bacteria.

Hooke, when coining the term cells, had technically discovered the cell wall in 1665. Human cells don't have a cell wall like plants and some bacteria, but they do have a cell membrane, a layer of lipids (fatty molecules), proteins and other components. Though it was clear that something must surround animal cells, it wasn't until 1855 that the doctor Robert Remak found a way of hardening the membrane so he could see it clearly.

Seventy per cent of the volume of the cell is cytosol, a colourless liquid that is mostly water, plus salts and organic molecules. Together with components

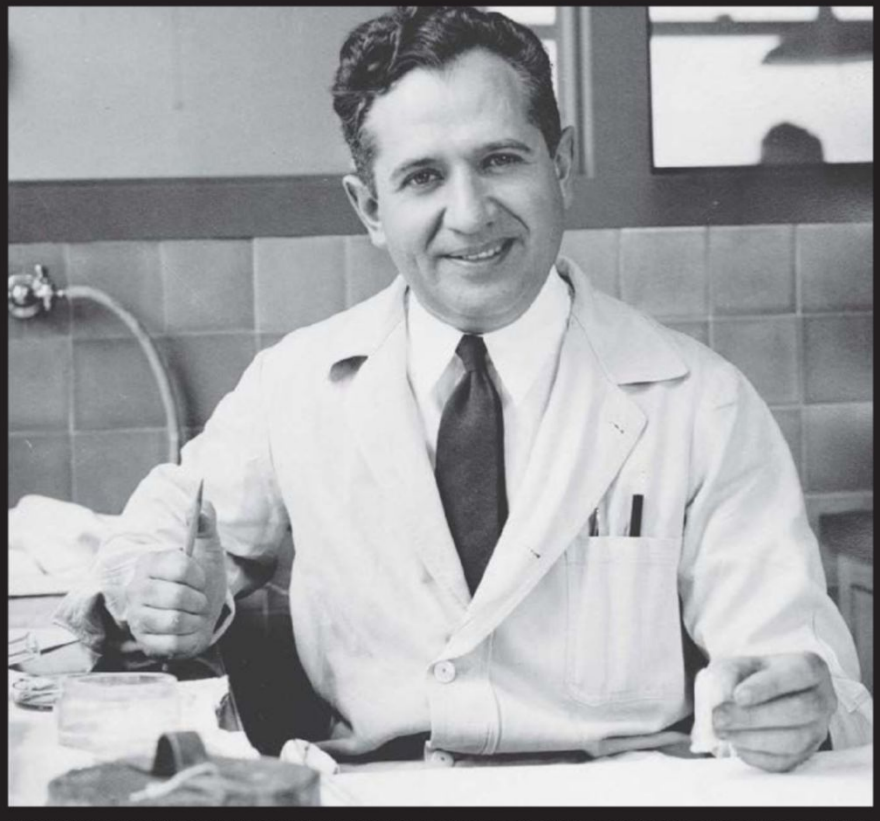
THE KEY DISCOVERY

Sometimes major scientific discoveries happen by chance, as Albert Claude found when he stumbled upon a key organelle while searching for a virus in the cells of a chicken

Much was known about the cell by the time that Albert Claude performed his key experiment of developing cell fractionation in 1930. But looking down a microscope was quite different to being able to separate out the parts of the cell to study them individually.

Claude developed cell fractionation while trying to isolate a virus, called Rous Sarcoma Virus, from chicken tumours. To do this he gently mashed up the tumour cells with a mortar and pestle (or sometimes a commercial meat grinder) to break the membranes and release the cell contents. He then put them in a tube and spun them in a centrifuge, the force of which speeds up the settling of heavier particles to the bottom of the tube. By successively spinning and extracting the sediment, the components of the cells are separated by size.

Claude found what he was looking for: a virus made of Ribonucleic acid (RNA). Good scientists run 'control' experiments too. In this case, Claude needed to show that the virus was present in only the tumour cells, and not healthy chicken cells. But when he repeated the process, he found that healthy cells also had similar RNA-rich particles in them. He named these mysterious organelles 'microsomes', discovering for the first time an organelle that researchers using a light microscope simply wouldn't have spotted.



Albert Claude serendipitously discovered microsomes, a cell organelle, when searching for a virus using a centrifuge

PHOTO: ROCKEFELLER ARCHIVE CENTER, SCIENCE PHOTO LIBRARY X2, SCIENCE & SCOIETY, CORBIS, ALAMY

called organelles, cytosol makes up the cell's cytoplasm – everything in the cell membrane aside from the nucleus. Around 1835 the French biologist Félix Dujardin saw this 'life substance' in single-celled animals and named it sarcode (meaning 'the flesh of the cell').

In the mid-19th Century life was made a little easier for the nascent field of cell biology. Until this point a variety of natural dyes such as iodine, cochineal and van Leeuwenhoek's saffron had been used to stain cells. But in 1856, a young assistant chemist named William Perkin produced mauve, the first synthetic dye. Though not designed for cells, it was the first of many useful synthetic dyes.

Internal organelles

Many cellular metabolic processes take place in the cytosol, but some occur in dedicated organelles. One of the best-known organelles is the mitochondrion, now known as the cell's 'powerhouse' because it produces a molecule that is used as a source of chemical energy. It's possible that mitochondria were first seen in muscle cells by the Swiss physiologist Albert von Kölliker in 1857. But it was Richard Altmann, in Germany in 1894, who established that they were organelles and called them 'bioblasts'. They were renamed mitochondria by the German cell biologist Carl Benda in 1898.

Another organelle was discovered as a direct result of cell staining, and is also the only one to bear the name of its discoverer. In 1897 Camillo Golgi discovered an organelle called the Golgi apparatus in a makeshift lab he'd set up in a small hospital kitchen. It was there that he developed the 'black reaction' in which cells are impregnated with silver nitrate, highlighting their contents under the microscope. The Golgi appeared as a fine network inside the cell, and we now know that it is involved in the packaging up of proteins and lipids made by the cell.

As the 20th Century dawned, most of the large components of the cell had been spotted and named. However, really getting to grips with what each part of the cell did was going to take more than looking. As the Belgian cell biologist Albert Claude said in his 1974 Nobel

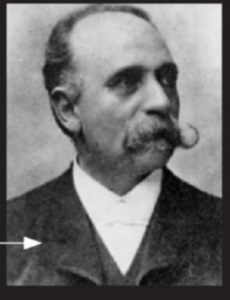
CAST OF CHARACTERS

The great minds who harnessed cutting-edge technology of the time to explore cells

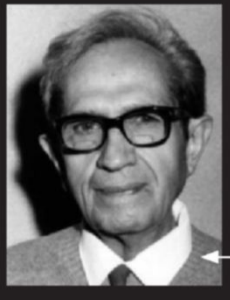
Robert Hooke (1635-1703) contributed to fields as diverse as architecture, palaeontology and astronomy. He was an English researcher born in the Isle of Wight and known for his difficult manner and rivalry with fellow researcher Isaac Newton.

Antonie van Leeuwenhoek (1632-1723) was a Dutch draper and amateur researcher. Son of a basket maker, he was an unlikely scientist, but his skill led to him producing some of the most advanced microscopes of his time, and the discovery of single-celled organisms.

Theodor Schwann (1810-1882) was a German physicist born in the town of Neuss. He was most productive early in his career, making discoveries in digestion, the nervous system and metabolism, before turning his attention to theology later in life.



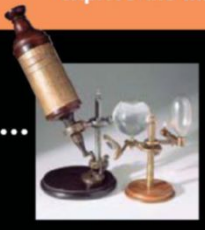
Camillo Golgi (1843-1926) was an Italian doctor and researcher. He concentrated his work on the nervous system though he also strayed into malaria research. Many of his discoveries are named after him, as is the village of his birth.



Albert Claude (1899-1983) moved to the United States in 1929. He was a Belgian cell biologist who served for the British Intelligence Service during World War I, and was rewarded with a medical education in Belgium despite not having the required qualifications.

TIMELINE

The advent of the microscope enabled biologists to explore the inner space of the human cell



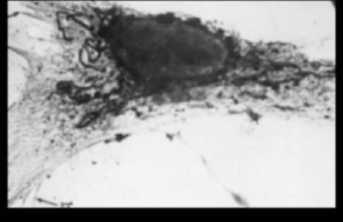
1665 — Robert Hooke's *Micrographia* is published, in which he describes using a microscope to find boxy structures in a thin slice of cork and coins the term 'cell'.

1675 — Antonie van Leeuwenhoek uses his powerful microscope (pictured) to discover 'little animals' — single-celled organisms — in rainwater, followed by bacteria from his own tooth scrapings in 1683.

1837 — Matthias Schleiden and Theodor Schwann discuss the recent discovery of the nucleus and realise that both plants and animals must be made up of the same basic units: cells.

1897 — Camillo Golgi discovers the Golgi apparatus in nerve cells using the 'black reaction', his own staining technique which involves impregnating cells with silver nitrate (pictured).

1939 — Albert Claude develops the technique of cell fractionation in an attempt to isolate a chicken virus. He discovers ribosomes and isolates mitochondria in the process.



1945 — Claude and colleagues produce the first electron microscope image of a cell (pictured), which George Palade describes as "cell biology's birth certificate".

PHOTO: SCIENCE & SOCIETY, SCIENCE PHOTO LIBRARY X2, CORBIS, ALAMY, ROCKEFELLER ARCHIVE CENTER

lecture: "Until 1930 or thereabout, biologists, in the situation of astronomers, were permitted to see the objects of their interest, but not to touch them; the cell was as distant from us as the stars and galaxies."

Peering deeper

At the same time, the tool that had been their window into cells – the light microscope – was coming to the end of its usefulness, unable to resolve objects smaller than the wavelength of light.

Two techniques developed in the first half of the 20th Century would come to the rescue, revealing structures invisible to the light microscope, confirming previous findings, and working out the biochemical role of organelles. The first of these, cell fractionation, allowed scientists to get their hands on cellular components. Developed in 1930 by Albert Claude at the Rockefeller Institute in the United States, it involved mashing up cells and then using the process of centrifugation to separate their subunits (see 'The key discovery').

The second essential technique was electron microscopy, invented by German engineers in 1931. Physicists were already using the technology, but it was Claude who brought it into the realm of biology. Electron microscopy uses a beam of electrons as a source of illumination and can resolve much smaller objects than traditional microscopes because the wavelength of an electron is much shorter than that of a photon (a packet of light). In 1943 Claude began working with one of the few electron microscopes in the United States to look at subcellular particles produced by cell fractionation. In 1945, his lab was the first to use an electron microscope to image a whole cell. George Palade, who shared the Nobel Prize in 1974 with Claude and the Belgian researcher Christian de Duve, later called this image (see left) the "birth certificate" of cell biology.

Claude's lab was able to combine these techniques to determine what mitochondria do; they may have been observed and named in 1894, but it was only once they had been isolated that researchers could find out their function.

NEED TO KNOW

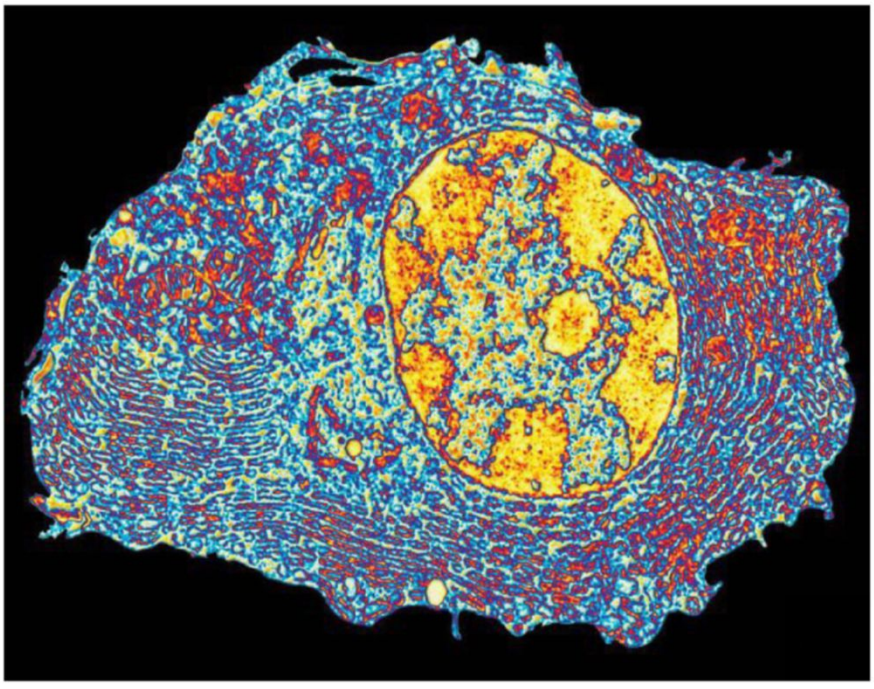
Key terms to help you understand the workings of cells

1 CELL
The basic unit of life — everything is made up of cells. Human cells have genetic-material containing a nucleus and membrane-enclosed organelles, all in a watery substance called the cytosol and surrounded by a cell membrane.

2 EUKARYOTIC
A type of cell which has a nucleus and membrane-enclosed organelles. Plant, animal and fungal cells are eukaryotic, as are some single-celled organisms.

3 ORGANELLE
A component of the cell that has its own specialised function, in much the same way that an organ plays a specific role in the body. They are often separated from the cell by their own membrane.

4 PROKARYOTIC
A type of cell with no nucleus, mitochondria or other membrane-enclosed organelles. Most prokaryotes are single-celled organisms, such as bacteria.



A cross-section of a human cell taken with an electron microscope reveals the nucleus (large oval centre) surrounded by cytoplasm. This is filled with the endoplasmic reticulum (ER) – seen as a pink network

He found that they contained many enzymes (proteins that act as catalysts) associated with the chemical process of respiration, and that they are indeed the cellular power plants. He also used characteristic dyes to conclude that the organelles in his test tube were the same that had been seen under the microscope.

Also in 1945 Claude, along with colleague Keith Porter, used electron microscopy to discover the endoplasmic reticulum (ER), a large membranous system within the cell that is involved in producing proteins and lipids, and transporting them around the cell. The net-like structure had initially been spotted in 1902 by the Italian scientist Emilio Veratti, but the idea was discarded by the scientific community at the time.

In 1946, George Palade joined Claude's lab and began to refine many of his techniques. It was Palade who realised that the microsomes that Claude had discovered in his key experiment can be part of the ER. He renamed them ribosomes in 1955, and found that they produce proteins. We now know that the membrane of the ER joins up with the outer membrane of the nucleus, providing a highway along which DNA is translated into proteins. Part of it, the 'rough' ER, has ribosomes attached, and another, the 'smooth' ER, produces lipids.

Waste disposal

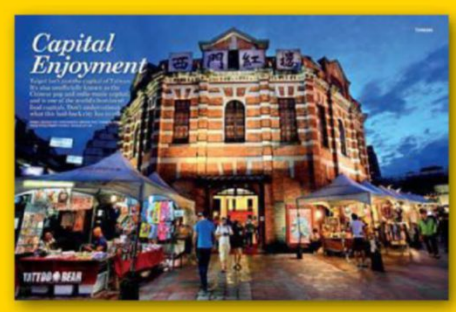
Christian de Duve, a Belgian researcher born in England during World War I, took these new techniques further by discovering an organelle without using a microscope – he didn't even have one in his lab at the time. In 1949 de Duve discovered lysosomes – the waste disposal unit of the cell – by accident when researching insulin in rat liver cells. He used cell fractionation and then biochemical tests to determine that the cell's cytoplasm contains numerous lysosomes – membranous particles of enzymes playing a role in cell communication and energy metabolism, as well as breaking down cellular components.

Researchers have discovered much more about the cell since the mid-20th century. But it's fair to say that today's cell biologists are more preoccupied with how the components work together than finding new ones. They tease apart the relationships between these cellular subunits – how they talk to each other to keep the delicate equilibrium of the cell's workings in check; how they behave in certain circumstances, and how this knowledge can be exploited to develop drugs and other treatments.

It is now possible to watch living cells go about their business, using the modern versions of van Leeuwenhoek's saffron to watch specific parts of the cell in action. Today's image of the cell is dynamic – a high-definition film to the 17th century's hand-drawn sketch.

KATHERINE NIGHTINGALE is a science writer with a degree in molecular biology

In this issue



- **Getting reacquainted with Taiwan's poster girl, also unofficially known as the Chinese pop and indie music capital**

- **We delve into the Tasmanian magic of splendiferous landscapes, discovering beauty, art and excellent produce**

- **For the uninitiated, the island of Oahu, Hawaii, home to the state capital of Honolulu, is a good place to start**

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TIME TO SWITCH OFF?

Your morning TV, your smartphone commute, the office desktop and your home laptop: you probably spend more time staring at a screen than you think. But is it bad for you? Holly Cave investigates

Two workers sit together at a desk; three-dimensional shapes shimmer in the air in front of them. One reaches into the design, altering it with a fingertip before flicking it over to her colleague. The mist-like apparition moves as they move, switching seamlessly between the air in front of their faces and the interactive table top.

This futuristic scenario is not science fiction, but exists as a working prototype created by researchers at the University of Bristol's

PHOTO: THINKSTOCK

Interaction and Graphics Group. Formed by a curtain of fine water droplets, MisTable's see-through and reach-through 'screens' are not just a spellbinding novelty – it's hoped they could solve many of the health problems associated with today's electronic devices.

Digital eyestrain

Many of us feel the effects of screen use on our eyes. Blurred vision, headaches and burning, itchy, sensitive eyes are some of the host of uncomfortable symptoms captured under the umbrella term Computer Vision Syndrome, or digital eyestrain.

Given the time some of us are now spending focused on a screen, it's perhaps no surprise that this problem is so common. As you might expect, research has shown that digital eyestrain is directly associated with the length of time spent looking at screens – the longer you use them for, the more likely you are to develop the symptoms.

"Some people hold their phones as close as seven or eight inches away. You'd never hold a book that close"

But is staring at a screen any worse than running your eyes over information on the printed page? For certain problems, such as dry eyes, research suggests it is. When we're looking at screens, we tend to stare straight ahead rather than down, as we might when reading a book, resulting in a larger surface area of our eyes being exposed to the drying effects of circulating air. We also seem to blink less often when processing information from screens, compared to paper. This means our eyes are less regularly moistened by tears.

"People are spending hours and hours looking at screens," says Mark Rosenfield, a vision scientist based at the State University of New York. "Some people are approaching 12 to 15 hours a day on these things. Typically, people simply don't look at printed materials for that long."

"But I don't know if computer vision syndrome is caused by the screen itself or by the way people are looking at them, for a couple of reasons," he says. "Firstly, the print often is pretty small – especially on smartphones – and people tend to hold them at very close distances. We've found that some people are holding their phones as close as seven or eight inches away. You'd never hold a book that close and this means the eye has to work a lot harder than if it was looking at larger print further away."

He counters that recent reports of screen use causing myopia, or short-sightedness, are as yet unfounded – "though I think kids especially are spending a lot more time looking at screens than they would be reading. So it's possible this does lead to short-sightedness, just by virtue of the length of time they're spending on their devices."

Of course, anyone who owns an eReader will tell you that an eInk screen is kind to your eyes and will spare you any side effects, and to a degree, they're right. Since eInk doesn't require a backlight to work, it taxes the eye less. Indeed, in the lab, researchers

Paper-like screens are less problematic

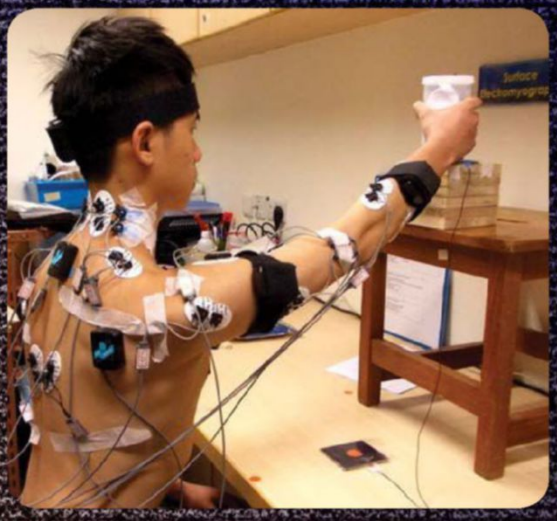
Never mind the blue screen of death, what about the blue screen of chronic insomnia?

80%

of 'Millennials' (people aged 13 to 32) sleep with their mobile phones next to their bed.

PHOTO: DR GRACE SZETO/CHINESE UNIVERSITY OF HONG KONG, GETTY X2, ALAMY X2

Monitoring smartphone usage habits at Grace Szeto's laboratory



Physiotherapist and screen use researcher Grace Szeto

repeatedly find that there's no subjective or objective (number of blinks made by the reader) difference in the fatigue experienced while reading an eBook compared to a printed one. But that isn't the end of the story.

Researchers from the Reading Centre at the University of Stavanger, Norway had a hunch that using an eInk screen might be changing our reading habits. In an experiment they gave volunteers a short story to read – half read it on an eReader while the others were given a physical book. A week later they invited the participants back for a simple test: retell the story's events in chronological order. As suspected, the print readers were able to recall the events of the story more accurately than their eReading counterparts. Although it's not clear why the digital readers had a more porous memory, it's clear that

2/3

of people using computers for at least two hours a day report eye problems associated with Computer Vision Syndrome, or digital eyestrain.

THE EFFECT ON SLEEP

Not getting your full eight hours? Taking your phone to bed could be the problem

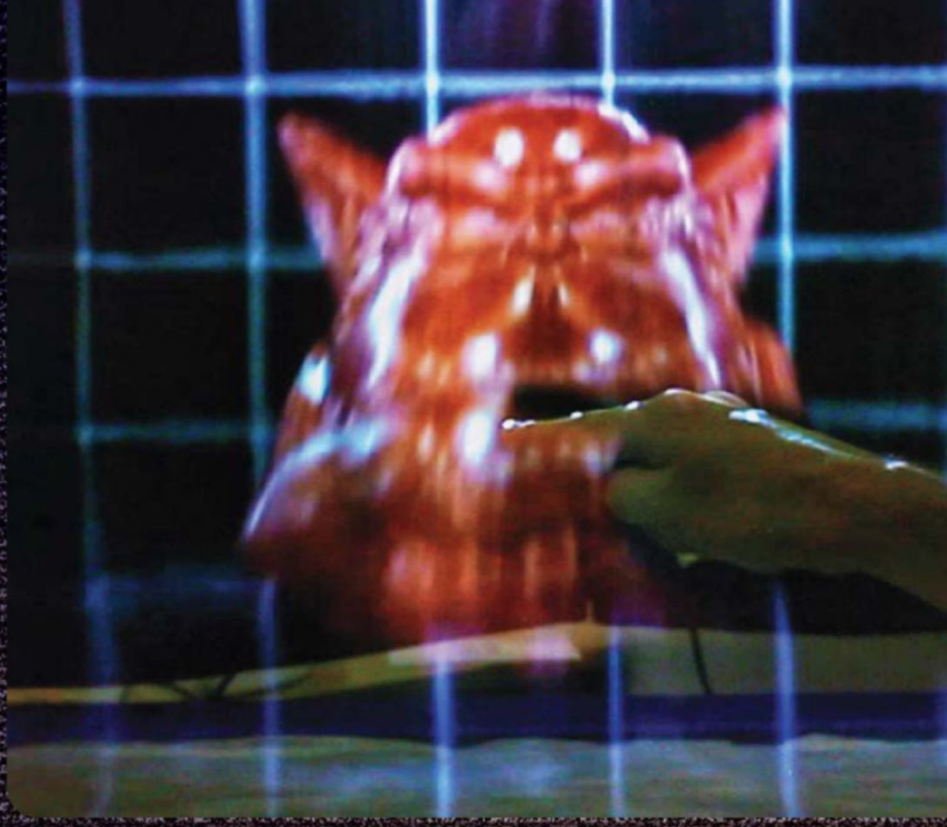
Neurologists have known for years that staring at screens late in the evening can disrupt sleep. Yet more and more of us are taking mobiles and tablets into the bedroom, where we hold them right in front of our eyes for extended periods of time before we try to nod off.

Browsing Facebook on your tablet disrupts your body's circadian rhythm – its ability to "do the right thing at the right time" – says Mariana Figueiro of Rensselaer Polytechnic Institute's Lighting Research Center. Playing our favourite game not only makes us feel alert when we should be winding down, but also fires blue light at our retinas. Shorter in wavelength than the white light produced by lamps, it stops our bodies from producing the sleep hormone melatonin. The pineal gland would normally start to release melatonin into the bloodstream a couple of hours before our typical bedtimes, signalling 'lights out' to our body.

Not noticed this effect? Figueiro's research shows that some people are more sensitive to light than others. Data from her lab suggests that melatonin is suppressed to a greater extent in teenagers than in university students, for example.

And the knock-on effects of delayed and disrupted sleep may stretch far beyond making it hard to get up in the morning. "Long-term suppression of melatonin has been linked to sleep disorders, which in turn have been linked to diabetes and obesity," Figueiro adds. "In animal models, prolonged suppression of melatonin and disruption of circadian rhythms has also been linked to an increased risk of cancer."

Put tablets away an hour before lights out if you want a good night's rest



screen reading seems to be altering our reading habits. In a similar vein, an analysis of reading patterns by San Jose State University, revealed that when faced with an LCD screen, readers bolted around the page, scanned for keywords and only read certain sections. They were using well practised strategies for digesting information rapidly, abandoning the kind of "deep reading" we employ when reading a book. Whether or not these changes have any root in the brain is yet to be seen, but these results do hint at a deeper relationship between screens and our literacy.

"When it comes to multi-touch devices such as smartphones, the thumb is under a lot of stress"

Too tense

What about the physical effects? If someone tells you they've got tennis elbow, it doesn't necessarily mean that they've been sweating it out on the court. Along with carpal tunnel syndrome and tendonitis, it's just one of the physical problems that can result from using screen-based devices. Pain in the neck is linked to muscle tension, joint compression and poor posture when looking at screens. Wrist and forearm pain is common, too, and Grace Szeto's research is showing that our increasing use of small touchscreen devices such as smartphones can affect our fingers in particular.

"Problems in the neck and shoulder region are related to static posture, whereas problems in the wrist and finger region are due to the highly repetitive movements performed in using touchscreen devices," says Szeto, a professor of physiotherapy at Hong Kong Polytechnic University. "When it comes to multi-touch devices such as smartphones, the thumb is under a lot of stress. Repetitive movements can lead to De Quervain syndrome – inflammation in the tendons at the base of thumb. For people who use their index fingers to interact with their phones, then the joints in that finger may suffer increased stress."

Szeto's research shows that factors such as screen size, the weight of the device and how it is held all affect the muscles in different ways. So are some people naturally more prone to these problems?

"There is research to suggest that people who tend to have tense muscles, or those with mental stress, may be more affected," she says. "But this is an association rather than cause-and-effect. People that report pain are observed to have high muscle tension, but it's difficult to prove which starts first."

17%

of boys spend more than three hours a day playing computer games, according to the GoWell East Study of Physical Activity in Secondary School Pupils in Glasgow in April 2014.

The same study reported that a similar number (16%) spend more than five hours online every weekend.

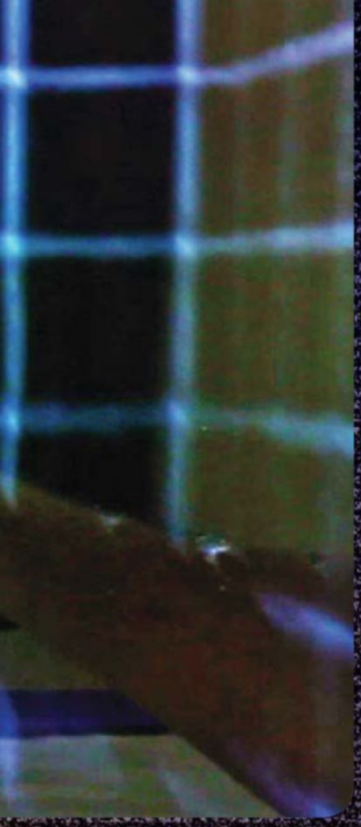
Screen blues?

It's been suggested that screen time may damage our mental health as well as our physical health, but the complex psychology involved makes it difficult to analyse.

A 2013 Public Health England (PHE) report looked at the behaviour of children in particular, drawing from several research papers to conclude that "increased screen time and exposure to media (such as bedroom TVs) is consistently associated with reduced feelings of social acceptance, and increased feelings of loneliness, conduct problems and aggression."

It's also been suggested in the past that internet usage leads to a decrease in general wellbeing and an increase in depression. But when Erik Wästlund, a psychologist based at Karlstad University, recreated such studies back in 2001, he concluded there was no direct

PHOTO: UNIVERSITY OF BRISTOL X3, GRIPSENSE



Developed at the University of Bristol, MisTable is a new kind of interface that aims to reduce problems caused by staring at screens all day

GripSense is an ergonomic iPad case designed to prevent wrist strain

connection between screen time and depression. He thinks the issue is "more about age and adolescence, with the general pattern being that younger people tend to spend more time on the internet and also happen to report lower psychological wellbeing."

But what about working adults? "Always being connected makes it difficult to differentiate between work and leisure time," Wästlund says. "Being in a more or less constant work mode never gives you time to recuperate. And by occupying every dull moment with an e-device, be it with apps, social networks, or news, we never allow ourselves to process and incubate information."

A healthier future

Common advice for regular screen users is to get regular eye tests, and while working from a screen to look into the distance, taking breaks every so often. With smaller devices, it's best to hold them higher to avoid neck strain, use both hands, support your forearms and change posture regularly.

Bristol's prototype screen makes this much easier. "These recommendations can be done in MisTable by focusing on the objects behind the partially transparent fog screen," says the prototype's co-creator Diego Martinez Plasencia. "So some elements in our setup could really benefit this kind of attention-intensive, visual display unit-based work. At the same time, these scenarios rely heavily on the specialisation and previous experience of the workers with this type of interaction, so it is something that will happen slowly and incrementally."

A survey of 2,000 people suggests that those aged under 25 check their phones

times a day, with

43%

experiencing anxiety when they can't check it.

But the good news is that we won't have to wait for a paradigm shift from screens to virtual reality or swirling, Minority Report-style interfaces for things to improve. Incremental changes are being made all the time. E-readers, for example, are getting closer and closer to mimicking the feeling of reading from paper. "The clarity of the image on LED screens is getting better too," adds Mark Rosenfield. "Going back 10 years, screens were pretty awful." And manufacturers themselves, such as Microsoft, HP and Amazon, want to improve the situation. Parts of Jay Kim's research, for example, are funded by such companies.

"While there haven't yet been any solutions that have been scientifically validated," says Kim, "many of the problems arise from the fact that there is a lack of tactile feedback on those devices, and because hands and fingers cannot be rested on the touchscreen keyboards. If more robust multi-touch and haptic technologies are developed, allowing people to rest their hands on the screen and get accurate feedback on touch and location, many problems can be addressed and reduced."

Mayank Goel, a computing researcher at the University of Washington, is developing systems which adapt to the user's posture, including GripSense, a pressure- and motion-detecting system, and ContextType, an adaptive text entry system. These ideas could help reduce musculoskeletal problems for touchscreen users, not by changing the screen itself, but by making the device learn the user's natural typing pattern to ensure that they are not forced to extend their hands and fingers to a static location.

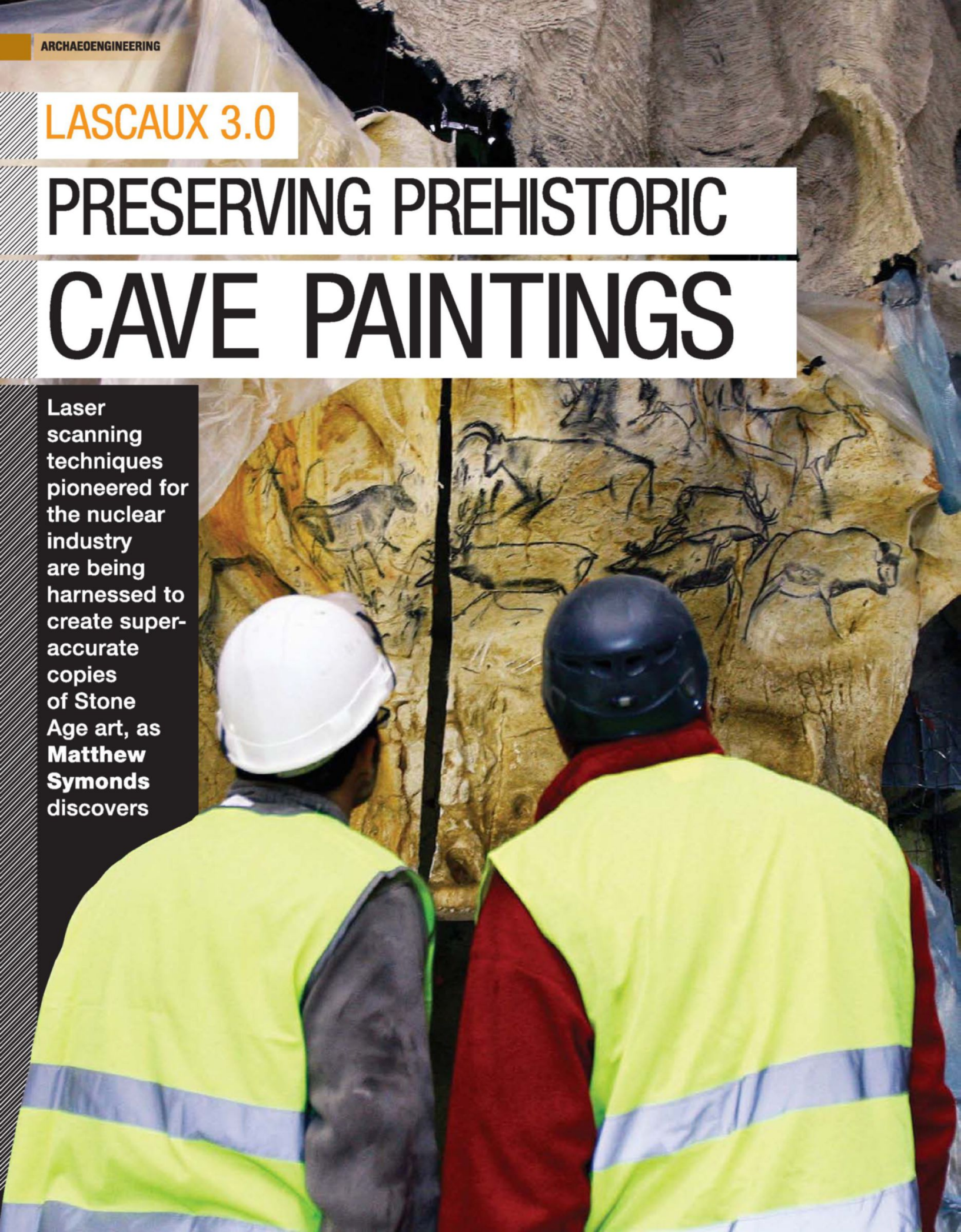
"If a keyboard makes it easier for you to type, or if it adapts to your posture, then potentially, you don't need to stretch your hands across big touchscreens," he says. "More research needs to go into exactly how much the user would benefit, but I'm sure that a lot of repetitive stress injuries can be lessened by making our devices more aware of how we're using them."

HOLLY CAVE is a freelance writer and author of the children's book *Really, Really Big Questions About Science*

LASCAUX 3.0

PRESERVING PREHISTORIC CAVE PAINTINGS

Laser scanning techniques pioneered for the nuclear industry are being harnessed to create super-accurate copies of Stone Age art, as Matthew Symonds discovers



The discovery of the Lascaux cave complex has all the ingredients of a Boy's Own adventure. In September 1940, just a few months after France's surrender in the Second World War, four teenagers entered a natural cleft in a Dordogne hillside. As they ventured deeper into the darkness, it quickly became obvious that they were not the first to have been drawn to this underworld. Daubed on the living rock, in vibrant hues of russet, black, and yellow, were paintings of majestic creatures that had roamed the hills thousands of years before. The boys had stumbled across one of the most spectacular decorated caves ever found.

Those first four visitors in 1940 marked the start of a flood. Between 1948, when the cave opened to the public, and 1963, over a million tourists flocked to Lascaux. But inundations of up to 2,000 visitors a day took a toll on the delicate subterranean environment. The combination of artificial lights and crowds breathing out carbon dioxide allowed algae and bacteria to flourish. By 1963 a veil of green algae was attacking the prehistoric paintings and the decision was taken to close the cave.

Public appetite for the ancient artwork remained undiminished, though, and so part of the cave was recreated in a nearby quarry. Lascaux 2, as it became known, was a labour of love for Monique Peytral, who spent a decade in the 1970s and '80s manually recording and then replicating a portion of the cave

"A point cloud could be created, and then worked up into a life-size physical model"

Francis Ringenbach, head of artistic production, Périgord Facsimile Workshop

PHOTO: SYCPA

While recreating the caves was a high-tech process, the paintings themselves were redrawn by hand

OLD MASTERS

Why the cave paintings were made is a 17,000-year-old mystery

Why prehistoric people transformed Lascaux into an underground art gallery is a mystery. Discarded stone lamps show the artists were able to toil away from natural light, while hollow rocks still bear traces of the powdered pigments used to create their compositions. Radiocarbon dating suggests that the paintings were created about 17,000 years ago. This makes them almost four times older than the pyramids of Giza, and sets them in the era of the Cro-Magnons: anatomically modern humans living a hunter-gatherer lifestyle in late Ice Age Europe.

Nearly 600 painted animals and a further 500 abstract motifs adorn the walls of Lascaux. Horses are the most common subject, followed by stags and aurochs – an extinct species of cattle – then ibex and bison. Images of predators are in a minority, and banished to remote areas of the cave, suggesting that the animals were not placed randomly within this underworld. The sole painting of a human is a crude stickman. This figure is lying before a charging bison, its guts spilling out after being sliced open by a spear. As these paintings were made thousands of years before the dawn of a written language, we cannot know for certain what they mean.

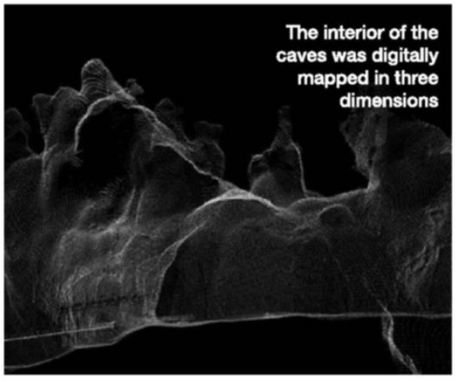
Every detail of the caves' shape has been recreated in painstaking detail

complex. In 2007, work began on creating five facsimiles of sections that did not feature in Lascaux 2, for the Conseil Général – the local council – in Dordogne. Dubbed Lascaux 3, this project employed state-of-the-art technology that Ms Peytral could scarcely have dreamed of.

Underground art

Lascaux 3 drew on a virtual 3D model of the cave, which was captured using a portable scanner that projected a laser beam across the cavern walls. This technique was originally developed as a hands-free way to survey nuclear power stations. When the beam strikes a surface it is reflected back to the scanner, allowing the point of impact to be recorded as a single dot at a known distance. As the survey continues, a cloud of these points builds up, creating a detailed digital model of the scanner's surroundings.

When the survey of Lascaux was complete, the nooks and crannies of its undulating passages and galleries had been recorded to an accuracy of a fraction of a millimetre. The prehistoric artists'

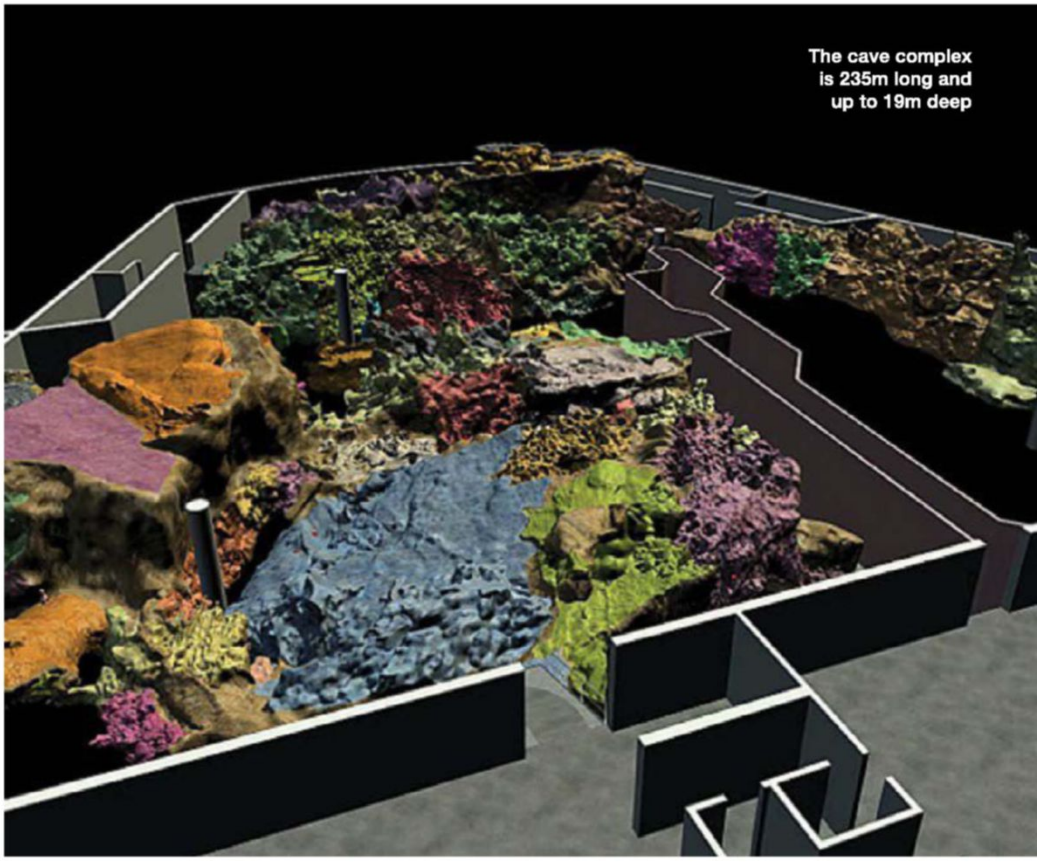

The interior of the caves was digitally mapped in three dimensions


The stone veil: each section consists of a mineral veneer on a fibreglass frame


Installing the framework on which the stone veil is mounted


Mounting the stone veil panels onto the metal framework

The paintings were recreated using the same pigments as the originals



The cave complex is 235m long and up to 19m deep

canvas could now be simulated with breathtaking clarity, but their handiwork posed a greater challenge, as the paintings are essentially flat. To complete the virtual version of Lascaux, high-resolution photographs of the artwork were layered onto the 3D model.

To craft the five Lascaux 3 panels, this mass of survey data needed to be returned to a physical form. "A point cloud could be created, and then be worked up into a life-size physical model called the matrix," explains Francis Ringenbach, head of artistic production at Périgord Facsimile Workshop, which created the replicas. A high-pressure water jet carved the cave contours captured by the laser scanner into a polystyrene block. Next, a negative impression of the rock face was cast in plastic.

In order to then replicate the texture of the rock accurately, the team developed what they call the 'stone-veil' technique. This involves applying a thin coat of clay, powdered limestone and other minerals to the plastic cast. The mineral veneer was then mounted on a fibreglass frame, creating a robust replica rock face that's less than half an inch thick.

Adding the paintings to these panels had to be done the old-fashioned way. A team of artists meticulously copied the ancient originals onto the simulated stone.

"We used the same pigments as the Lascaux artists. The main difficulties were technical"

Francis Ringenbach, head of artistic production, Périgord Facsimile Workshop

"We used the same pigments as the Lascaux artists," Ringenbach reveals. "The main difficulties were more technical than artistic. Artistically, the aim was to make an exact reproduction. The technical means evolved rapidly, and we were always left somewhat behind by the technological evolution, whereas the artistic part always stayed the same." In total, each of the five panels took around 1,800 hours to craft.

Unlike Lascaux 2, which lies immobile in its quarry, the Lascaux 3 panels are portable, and are currently the centrepiece of a travelling exhibition allowing audiences around the world to marvel at the skills of Lascaux's ancient artisans. Rapid obsolescence is, however, a hazard of modern technology. In 2016 Lascaux 3 will be superseded by Lascaux 4, a new, near-complete facsimile of the cave system. Part of a cutting-edge visitor attraction, it will lie at the foot of the hill where four teenagers set off on a grand adventure over three-quarters of a century earlier.

The stone veil had to be hand-tinted

MATTHEW SYMONDS is editor of *Current Archaeology* magazine. He can ask for a trowel in five different languages.

IS STRESS GOOD FOR YOU?

Scan this QR Code for the audio reader

Sweaty palms, a pounding heart and rapid breathing: we've all felt them. But symptoms like this may not be such a bad thing. Lilian Anekwe reveals the benefits of stress

ILLUSTRATOR: DANNY ALLISON

Researchers used karaoke singing, public speaking and a maths exam to study the effects of stress

PHOTO: BRANDON VICK/UNIVERSITY OF ROCHESTER X2 ILLUSTRATOR: DANNY ALLISON

Think of the last time you were in a stressful situation. If you felt the fear and did it anyway, was that in spite of the stress, or because of it?

We all know stress isn't good for you. We're told it's unhealthy and that we should remove it from our lives – if only it was that easy. But new research is forcing psychologists to think again. New evidence suggests that if we can learn to think about stress differently, then it can be useful, and even – believe it or not – good for us.

To be clear: persistent, unrelenting stress is bad. Ongoing stress consistently raises the levels of the hormone cortisol in our bodies, and over time this harms our health. Chronic stress can trigger headaches, musculoskeletal pain and gastrointestinal problems like irritable bowel syndrome. Stress has also been linked to depression and an increased risk of heart disease. But in the short-term, stress could be a power for good.

Take, for example, a recent study from the Harvard Business School, published in the Journal of Experimental Psychology: General. Their researchers found that in several different stress-inducing social situations – karaoke singing, public speaking and a timed maths test – people who felt excited by the stress performed better than those who remained calm. The stress had boosted their abilities.

You might argue that this is because some people simply cope with stress better than others. But that's only part of the story, as Prof Ben Fletcher, professor of occupational and health psychology at the University of Hertfordshire, explains. "Something like a job interview is a demanding situation and as such, the body will respond. Some people will find that stressful, others energising. I think that's because most people make a negative association between stress and the strain it causes on their body."

Fight or flight

When we're faced with tough situations, our bodies automatically react with a set of physiological changes known as the stress response. This arose in our ancient development as part of the 'fight or flight response', to help our ancestors deal with predators. In our modern lives, the threat of being eaten alive has been replaced by the 'threat' of deadlines or

Dr Jeremy Jamieson of the University of Rochester says it's not stress that's harmful – it's our attitude towards it

first dates. The trouble is, our bodies still react the same way: a pounding heart, sweaty palms and rapid breathing. And we nearly always view these negatively.

"If you tell people that stress is good for you, most people say that cannot be true," explains Dr Kelly McGonigal, a health psychologist and lecturer at Stanford University. "It's a pretty radical shift in thinking." But many psychologists and physiologists are now saying that the stress response is designed to help us, and that there's more to it than out-running threats.

"Unfortunately we have been convinced that stress is an enemy of our bodies," McGonigal adds. "Part of embracing stress is recognising that your body is not betraying you when you have a stress response. A lot of my work is teaching people what the stress response actually is. Everyone knows the fight or flight response, but that's just one aspect. What's even more mind-blowing is that the stress response tries to give you lots of different resources for dealing with difficulty."

"Part of embracing stress is recognising that your body is not betraying you when you have a stress response"

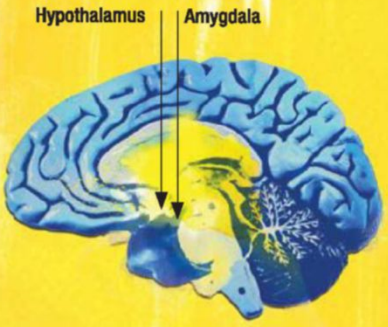
For example, when your body experiences stress it releases growth hormones, which make us stronger and more physically able to cope with demanding situations. The pituitary gland releases oxytocin and prolactin, which boost the immune system and protect the heart.

Positive thinking

If we have the right attitude, the body can help us feel good during times of stress. This is a crucial part of whether stress, put bluntly, kills us. An eight-year University of Wisconsin study of 30,000 Americans found people with a lot of stress had a 43 per cent increased risk of dying early – but only if they thought stress was harmful to their health. People who didn't believe stress affected them negatively didn't have this increased risk.

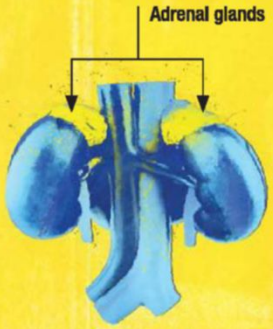
HOW THE BODY HANDLES STRESS

Confronted with a potentially difficult or threatening situation? Don't worry too much – your body's already gearing up to deal with it...



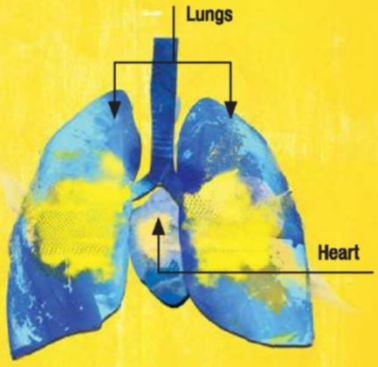
The brain

Our bodies' stress response begins in the brain. When we confront stress or danger, our senses send information to the amygdala, an area of the brain that interprets images and sounds and processes our emotional response to them. When it perceives a challenge, it instantly sends a signal to the hypothalamus. This is the body's command centre, communicating with the rest of the body through the autonomic nervous system so that it can deal with acute stress - before we're aware of it.



Adrenal glands

The autonomic nervous system controls involuntary body functions such as breathing, blood pressure, heartbeat, and the dilation or constriction of blood vessels and small airways in the lungs called bronchioles. The hypothalamus also activates the sympathetic nervous system by sending signals to the adrenal glands, which sit just above the kidneys. These glands respond by pumping the hormone adrenaline into the bloodstream.

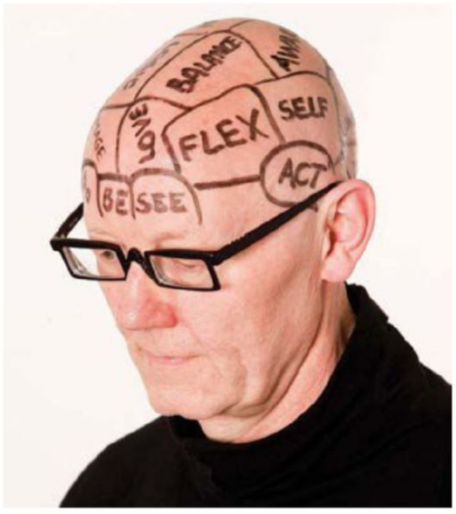


Heat and lungs

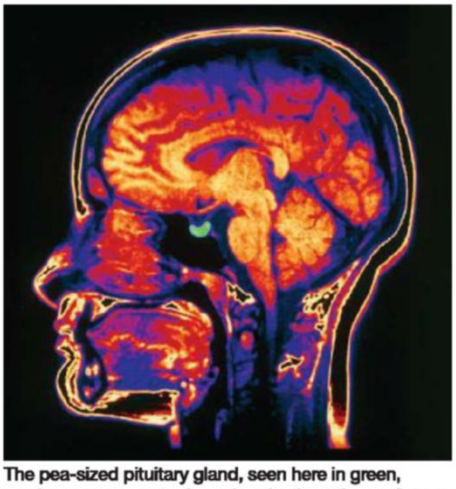
This brings on physiological changes. The heart beats faster than normal, pushing blood to the muscles, lungs, and other vital organs. This higher pulse rate increases blood pressure. We also start to breathe more rapidly, and the small airways inside the lungs open wider, to allow the lungs to take in as much oxygen as possible with each breath.

Fight or flight

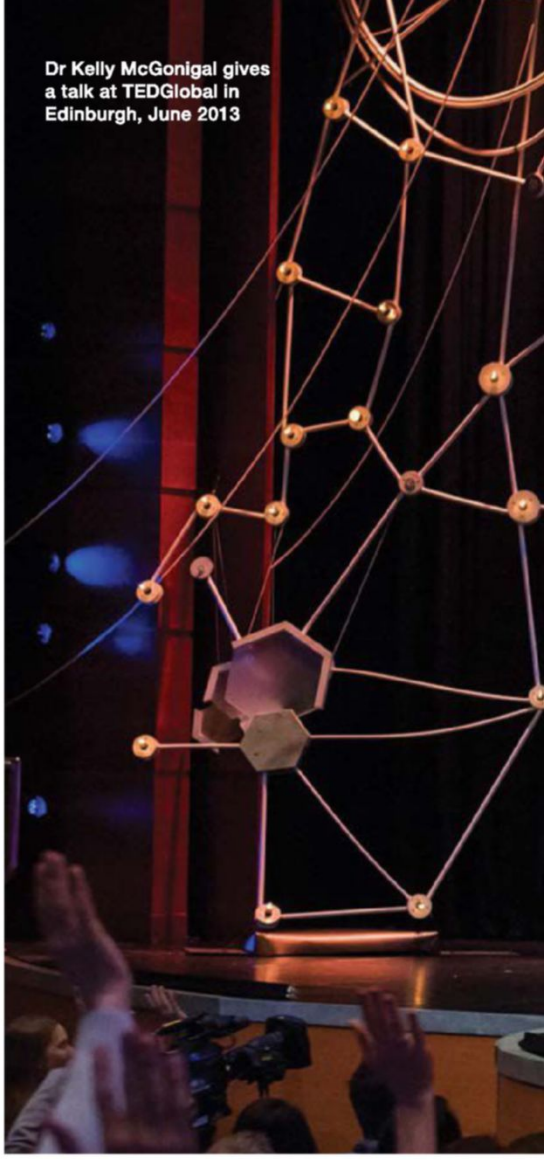
The extra oxygen is sent to the brain, increasing alertness. Our sight, hearing, and other senses become sharper. Meanwhile, adrenaline triggers the release of more blood sugar (glucose) and fats from the body's stores to give us more energy and nutrients. Our bodies are now better prepared to cope with physical challenges – whether they involve dealing with the problem (fight) or running away from it (flight).



Prof Ben Fletcher is Professor of Occupational and Health Psychology at the University of Hertfordshire



The pea-sized pituitary gland, seen here in green, produces more oxytocin and prolactin at times of stress



Dr Kelly McGonigal gives a talk at TEDGlobal in Edinburgh, June 2013

So it makes sense that the stress response also affects us psychologically. Research shows oxytocin encourages us to seek connections and support from our social network during times of stress. Socialising with others – particularly while doing good deeds – can help you become more resilient, which improves how we deal with stress.

This can have a long-term effect on 'killer stress', too. A University of Buffalo study found that every major stressful life experience increased an adult's risk of early death by 30 per cent – but not if they also spent a significant amount of time helping loved ones and neighbours.

Attitude adjustment

These studies show that there are two sides to stress, says McGonigal. "Even in the same situation, stress will have both positive and negative consequences. If you believe that all stress is inherently harmful and only focus on that, then you're going to interpret every stressful situation as bad. But people who are able to hold those opposites – who are also able to see positives, rather than focusing only on the negatives – seem to do best when it comes to stress."

Shifting people's thinking in this way is quite easy – in studies, at least. Dr Jeremy Jamieson, assistant professor of psychology

HOW TO EMBRACE STRESS

It's all very well saying 'accept stress as a good thing', but how do you do it? We asked an occupational psychologist

There are no easy fixes to change how we feel about stress, but Prof Gail Kinman, professor of occupational health psychology at the University of Bedfordshire, suggests we get used to how the body feels when we're under stress and when we're not, so we can recognise the difference as useful.

"Some people do well under pressure, others crumble. But no matter how we feel about it, the acute stress response was designed for short-term use only. You need to make time for breaks and recovery so that your stress response returns to normal. If you're constantly stimulated, then an elevated state can become the new normal. This impairs your body's stress response because you're constantly in a state of arousal."

This can affect our attitude to our stress response: instead of seeing it as transient and helpful, we see it negatively. "Seeking support from your social network is by far the best way of getting replenishment and recovery," Prof Kinman says.

In your downtime, choose things that challenge your body to cope with different situations. "There's value in using psychological and physical functions that you normally don't," Prof Kinman says. This can help us appreciate and value what we do, so during stressful times, we are less likely to see it as a negative.

PHOTO: TERRY RICHARDS, SCIENCE PHOTO LIBRARY, JAMES DUNCAN DAVIDSON/TED, THINKSTOCK

at the University of Rochester in New York, USA, led a study which showed that encouraging people to think of the stress response as positive can quite radically alter how they react.

Jamieson's group asked 69 adults to carry out two stressful tasks: performing a mental arithmetic test, and giving a five-minute talk about their strengths and weaknesses to a panel of seemingly disapproving observers with only a few minutes' preparation. Beforehand, half the group were given information that encouraged them to "reinterpret bodily signals as beneficial," as well as summaries of three studies that showed the benefits of stress. The other half were not given this information.

The group that had been prepped with the message that stress can be helpful said they felt they could cope with the situation better than the other group. They also had more dilated, relaxed blood vessels. Interestingly, people with social anxiety felt more intense feelings of anxiety during the stress test. "But their body's response was just the same as everybody else," Jamieson says. "It's just that how they were interpreting it was much worse than it actually was. How you interpret the increase in arousal – what your racing heart means to you – determines what type of stress you have."

"When we can take a positive view of stress we are less likely to feel out of control"

Dr Jamieson says recognising these physical reactions as the body's way of 'amping you up' to face a stressful situation can be a powerful way of turning stress to our advantage. "People have never been told that stress can be helpful," he says. "They don't recognise their stress response as an adaptive thing. This is a normal biological response, and it's there for a reason. Changing the way people think about what stress is can go a long way to helping them respond better. The better you get at using stress responses, the more efficient your body gets at them."

There are some simple ways to get the benefits of stress. In the Harvard research, assistant professor Dr Alison Wood Brooks found rather than trying to stay calm, simple strategies like saying "I am excited!" out loud made people approach their challenge as an opportunity, and improved their performance on the tasks.

"When we can take a positive view of stress we are less likely to feel inadequate, out of control or avoid things that create meaning in our lives," McGonigal says. "I'm not telling people to seek out stressful situations. But trust your body: it can and will do amazing things that will help you through short-term stress."

So next time you feel the fear in a stressful situation, embrace it. In the short-term, stress isn't going to break you – and it might even do you some good.

LILIAN ANEKWE is consumer health editor of *The BMJ* (formerly *The British Medical Journal*)

Babies learn the rules of ring-tailed lemur society by watching adults and, when older, by playing with other young in their crèches

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Photos by **Suzi Eszterhas**

Ring-tailed lemur society is ruled by a language of smells, displays and violence, and is teaching us about primate evolution, says Mike Unwin

SCRATCH & SNIFF

(Or, how to speak lemur)

Above: this baby is just two weeks old. All of the adult females carry the group's infants, often swapping them. Young are weaned at three months and independent at six months

It's a hot day in Berenty Reserve, south-east Madagascar, and there's a rumpus among the ring-tailed lemurs. Yips and squeals resound through the understorey as these spring-heeled primates bound around the roots of a tamarind tree. One young male advances with quivering tail arched forward over his head, only to be confronted by a rival doing exactly the same. In the shadows, a female performs a backwards handstand against a sapling.

To the enchanted groups of tourists watching these habituated lemurs, it looks like some kind of madcap primate circus. But, as their guides explain, the action is replete with meaning, and to catch the gist you need only learn the lingo. This means not only translating the lemurs' various yips, squeals, purrs, yells and wails, but also interpreting their sign language of posture, leap and grimace, and – even trickier to our untutored noses – their extensive repertoire of smells.

That's right: ring-tailed lemurs say it with stink, using scent to convey strategic messages about territoriality, social rank and sexual availability. Olfactory communication is far more developed in lemurs than among monkeys and apes, and especially so in this species, which produces a pungent secretion from an array of scent glands. There are some on the inner forearms (antebrachial glands), some on the shoulders (brachial) and yet more in the ano-genital region (perianal).

Those two tail-waving individuals were indulging in a 'stink fight' (see box, p75). The handstanding female, meanwhile, was marking the group's territory by smearing tree bark with scent from her vulva. A further glance around the group might also have revealed a male using special horny spurs on his wrists to gouge scent into the bark of saplings.

A most unusual lemur

"Madagascar's trademark" was how the celebrated primatologist Alison Jolly once described the ring-tailed lemur. Indeed, to people around the world it is emblematic of the island, and today that raccoon-like bandit mask and long black-and-white tail make the perfect symbol for the Madagascar National Parks Association.

Nonetheless, the ring-tailed is far from your typical lemur. For a start, it is much the most terrestrial of its kind – spending some 33 per cent of its time on the ground – and the most sociable, forming mixed-sex groups of generally 6–24 animals. It is also the most active by day, which makes it relatively easy to observe – and, crucially, to study. Jolly, who died this February, began researching the ring-tailed lemurs of Berenty Reserve in 1963, continuing the study for four decades.

Central to her research were communication strategies.

Right: a couple of young males scuffle. Generally, though, rivalries are less intense among the males than females

She discovered, for example, that ring-tailed lemurs use at least 28 vocalisations, ranging from soft contact calls, such as moans and meows, to howls audible from up to 1km away that advertise a group's presence to other groups in the area. Other sounds include contented purrs during grooming, chirps given when on the move, yips uttered by subordinates in the presence of superiors, and chutters given by a dominant individual upbraiding an inferior.

Taken in tandem with body language and scent-marking, this range of expression allows ring-tailed lemurs a complexity of social interaction that was once held to be the preserve of 'higher' anthropoid primates – that is, monkeys and apes. Indeed, studies of anti-predator warning strategies among ring-tailed lemurs have revealed that they employ a specific vocabulary to distinguish between threats. Thus shrieks warn of a passing Madagascar buzzard or another bird of prey, while yaps are used when mobbing a predatory mammal, such as the mongoose-like fosa.

Above: ring-taileds spend more time on the ground than other lemurs. Groups on the move hold tails aloft like flags to signal ownership of their territory

Ring-tails use at least 28 vocalisations, from moans and meows to howls audible 1km away

Learning the language of ring-tailed lemurs helped Jolly and her colleagues to unlock the secrets of their social life. It turned out that, in contrast with monkeys and apes, the lemurs live in a matriarchal society. While both males and females have separate dominance hierarchies within their sex, all females enjoy dominance over all males – a status that they readily assert by cuffing, lunging, biting and other displays of force.

Females stick together in their natal groups, with one high-ranking alpha female providing the central point for the group. Being the dominant sex, they maintain the group's territory – a fairly loose home range that overlaps with that ▶

Stink Fights

During the breeding season, male ring-tailed lemurs engage in stink fights to compete for females and resolve conflicts without resorting to violence. They anoint their tails with pungent perfume by rubbing the fur against the scent glands on the insides of their wrists and shoulders. Then they arch their smelly tails over their backs and wave them, to waft the fragrance towards their rival, hoping to deter him by sheer force of body odour. A stink fight breaks out when two males face off and start to pull their tails through these two glands. It lasts anywhere between 10 minutes and an hour, ending when one lemur backs down and flees.

Anointing the tail to prepare for a stink fight

How to see ring-tailed lemurs

Ring-tailed lemurs are confined to a handful of reserves and protected areas within nine separate forest blocks in south and south-west Madagascar. They are most easily observed in the dry, open forest at Berenty Reserve **(1)**, where the population density is high and lemurs are extremely tame, though you'll be sharing the experience with other tourists. Ring-tails may also be seen in the amazing-looking spiny forest at Anjampolo, north of Berenty, and at Isalo National Park **(2)**, among impressive sandstone rock formations.

Other sites include Andohahela National Park **(3)**, Zombitse-Vohibasia National Park **(4)** and Anjaha Community Reserve **(5)**. Look for groups sunning themselves in the early morning in open areas or on bare rock, adopting the distinctive 'lotus' or yoga position. Family groups are attracted to seasonal food sources – for example, in open forests in October and November they gather to eat the fruit and new leaves of the kily tree Tamarindus indica.

Feeding on the leaves of *ocotillo*, a succulent plant typical of the spiny forests in south-west Madagascar

of other groups. They will also take the lead in confrontations, driving off intruders with stares and other ritualised expressions of hostility. These interactions seldom lead to violence. Within their own troop, however, female dominance battles can turn ugly, resulting in serious injury or even expulsion.

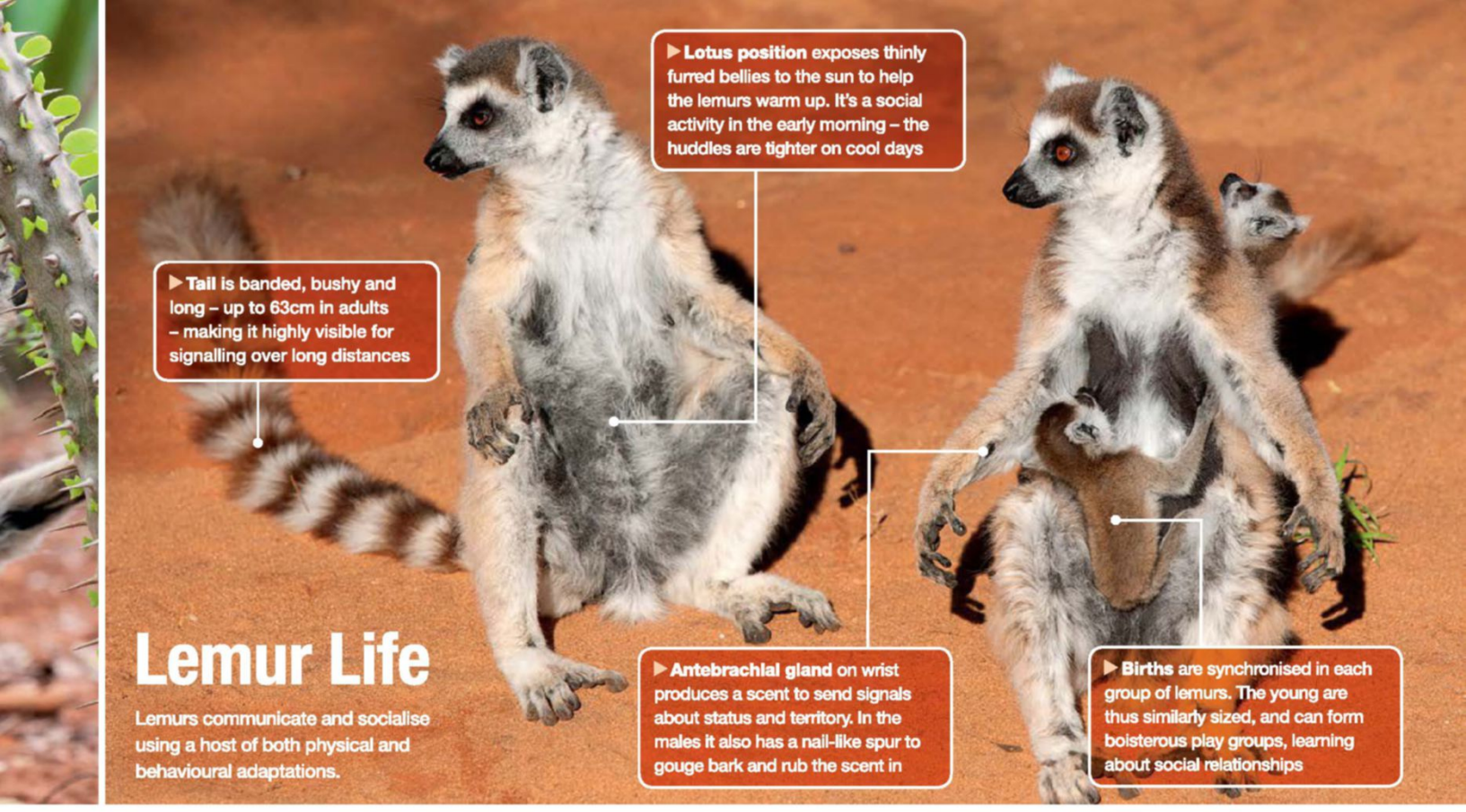
Dominance hierarchies among males are short-lived, and settled through stink fights and other ritualised displays. Competition is most intense during the breeding season, when it may erupt into 'jump fights' – rivals leaping into the air and slashing at each other with their canines. High-ranking males inhabit the centre of a group, where they associate more with females than with other males. Lower-ranking individuals hang around at the periphery and often switch groups in the hope of more success.

The breeding season is a frenetic three-week window from mid-April to mid-May, during which each female comes into oestrus for just four to six hours at a time. The group goes into social overdrive, males battling over mating rights and females copulating with multiple partners. The young – usually a single infant, or occasionally twins – are born in September. Females mature sexually at about three years; males leave the group when mature, and move between groups every three to five years for the rest of their life.

Jolly's studies have had implications far beyond her lemur subjects. "It seems likely that the rudiments of primate society preceded the growth of primate intelligence, made it possible, and determined its nature," she argued in a groundbreaking 1966 paper. At the heart of her thinking was the Social Intelligence Hypothesis: the idea that social intelligence – the collection of mechanisms such as politics, family relationships, quarrels,

Lemurs of both sexes (this is a female) do handstands to rub their anogenital scent glands against saplings

Ring-tails have a complexity of interaction once held to be the preserve of anthropoid primates – monkeys and apes



Lemur Life

Lemurs communicate and socialise using a host of both physical and behavioural adaptations.

collaboration and reciprocity that we see as integral to our own species – was the driving force behind the development of the large human brain.

Before Jolly's work, it was thought that evidence of early social intelligence could be observed in large-brained monkeys and apes, but that the smaller brains of lemurs made them irrelevant. It was her revelations about ring-tailed lemur society that first implied clues might lurk lower down the primate evolutionary tree. "Jolly was suggesting that primate social life provided the evolutionary context of primate intelligence," says Christoph Schwitzer of Bristol Zoological Society and the IUCN Primate Specialist Group. "Her work has helped us to unlock some of the mysteries of primate evolution."

More recent work with captive ring-tailed lemurs – for instance, at the Duke Lemur Center in North Carolina – has revealed cognitive skills never observed in the wild. These include the ability to organise sequences, understand basic arithmetical operations and use simple tools. The discovery of such capacities in more primitive primates suggests that they may have existed at an even earlier stage of primate evolution, though the skills did not emerge until much further down the evolutionary line, unlocked by the development of social intelligence.

Survival of a national icon

Who knows how much more there is to learn? Only last November, studies of ring-tailed lemurs living on the arid Mahafaly Plateau in south-west Madagascar revealed that these naturally forest-dwelling primates had adapted to living in limestone caves, where they find sleep sites safe from predation, refuges from extreme temperatures and a ready source of drinking water.

To study ring-tailed lemurs further, of course, there need to be subjects left to study. But with Madagascar's natural environment now under severe threat, this cannot be taken for granted. A 2014 update to the IUCN's Red List categorises 90 species of lemur (91 per cent of the known total) as at risk of extinction. Though the ring-tailed is one of the more plentiful species, recent drastic population declines have led the IUCN to 'uplist' it two categories from Near Threatened to Endangered – a rare event, says Schwitzer.

Habitat loss and degradation are the key threat. The island has lost 90 per cent of its original forest cover since the arrival of humans 2,000 years ago – and the process continues. Yet all is not lost. The IUCN is working on a new action plan. "With sufficient long-term funding and functioning institutions," says Schwitzer, "I am hopeful that we can secure the future of this wonderful lemur."

Meanwhile, according to Madagascar expert Derek Schuurman, ecotourism has a vital part to play. "The ring-tailed is the lemur that everyone wants to see," he points out, explaining how revenue ploughed back into the community provides an incentive for protection. Schuurman cites the success of the spectacular Anjaha Community Reserve, where villagers guide tourists through a small but pristine pocket of forest in search of ring-tails.

It's true that with an estimated 2,000 ring-tailed lemurs in zoos and collections worldwide, the species is not about to disappear. But on its island home it may have to adapt to survive. "Finding out how ring-tailed lemurs cope with deforestation and forest fragmentation will inevitably become a research focus," predicts Schwitzer.

It seems unthinkable that we might lose the ring-tailed lemur in the wild. It is, after all, the flagship for a nation. And as long as pungent stink fights and territorial battle cries enrich the air of the reserves it calls home, who knows what else this beguiling primate might teach us?

MIKE UNWIN is a naturalist and wildlife author. His most recent book is the Bradt Travel Guide to Swaziland.

THE GEOLOGY OF THE BRITISH ISLES

BY CHERRY LEWIS

By classifying the wide variety of rocks that make up Britain, an undertaking that took centuries to achieve, we've been able to tell the rich story of her geological past

Homo erectus first arrived in Britain around three quarters of a million years ago, bringing with them the ability to fashion crude flint tools, which were used in the butchering of animals. It was a time when Britain was still attached to Europe, by a landmass that eventually became submerged with rising sea levels at the end of the last ice age.

Over the following millennia, we Homo sapiens roamed the land looking for flints with which to make increasingly sophisticated tools. We also sought metals for weaponry, gold for decoration and stones for building religious sites like Stonehenge. Coal was important too, not just for smelting ores but for burning limestone to fertilise the land in order to secure a reliable supply of food.

During our search for these resources we accumulated an indigenous knowledge about where such assets might be found and the rock types in which they were located. Chalk, limestone, granite, sandstone, clay and many other rock types were probably recognised from very early times. But it was not until we really understood fossils that we could put this knowledge to best use.

In 1027, the Persian philosopher Avenica first outlined the foundational principle of geology. It stated that sedimentary layers are deposited in sequence, with the oldest on the bottom and the youngest on top. This 'law of superposition' was fully formulated in 1669 by the Danish scientist Nicolas Steno, who reasoned that strata were formed when particles suspended in water fell to the bottom, creating horizontal layers. Any deviation from the horizontal was due to a later disturbance. While Steno was not the only naturalist of his day to propose that fossils had once been living creatures, he argued for the first time that fossils were snapshots of life at different moments in Earth's history. Over the following centuries there were many opposing theories, but once these two principles had been established, the stage was set for a greater understanding of what fossils could tell us.

Black Church Rock in Devon exposes different layers of rock that have subsequently been tilted over time

Subterranean science

During the Industrial Revolution, Britain needed large amounts of coal and raw materials to be transported around the country. That led, in the mid 1700s, to a period of extensive canal-building. In 1794, the surveyor William Smith was supervising construction of the Somerset Coal Canal. Excavations started in July 1795 in a west-to-east direction along two parallel valleys, about 3km (1.8 miles) apart. As the excavations proceeded, they revealed the gently dipping strata one by one, allowing Smith to compare the layers in one branch of the canal with those in the other. This allowed him to work out the order in which the strata had been laid down. Furthermore,

PHOTO: AKG, GETTY

William Smith's geological map of Britain from 1815 reveals different rock strata in different colours

> IN A NUTSHELL

It was not until we realised we could use fossils as a time stamp that we were able to ascribe rocks to different periods. The genius of one man then enabled us to study their mineral content and describe Britain's geological past.

he noticed that each layer had a characteristic suite of fossils which "always succeed one another in the same order". It was therefore possible to match two strata containing the same suite of fossils, even though they were miles apart.

Using this method of correlating fossils, Smith was able to detail the 23 strata that lay between the Chalk (Cretaceous) and the Coal Measures (Carboniferous) in the area around Bath. This proved to be an advance of enormous magnitude, since his stratigraphic column provided a standard against which rocks anywhere in the country could be compared. Strata that had previously been given different names could be identified as being one and the same. When Smith realised he could make maps to display the strata by giving them different colours, he produced the first-ever large-scale geological map in 1799. He followed this map of Bath with the first geological map of Britain in 1815.

Smith's ideas spread quickly. By 1812, even before Smith had published his map of Britain, the metallurgist David Mushet had created a geological cross-section of the Forest of Dean coal basin. Mushet had come to the Forest of Dean in search of iron and coal, and his work correlated the different coal seams. He used data taken from strata revealed in boreholes across the region – boreholes drilled in the search for coal and iron. This early use of borehole data meant Mushet could also correlate rocks overlying coal seams in the Forest of Dean with those overlying coals in the Welsh, Bristol and Somerset coal basins. This enabled him to predict where coal might be found elsewhere.

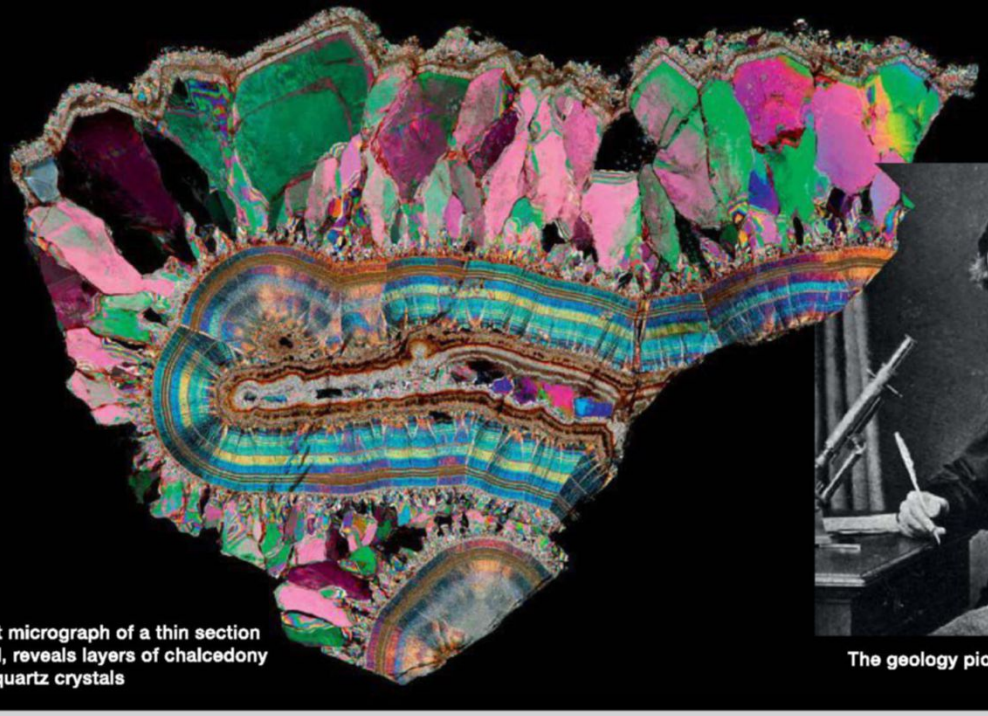
Despite these advances, geology was still an infant science. At that time, the word 'fossil' meant anything that had been dug out of the Earth and included minerals and archaeological artefacts as well as organic fossils. The word 'palaeontology' wasn't coined until 1822 and the word 'scientist' was first published as late as 1834. It's telling that in 1804, when writing

THE KEY DISCOVERY

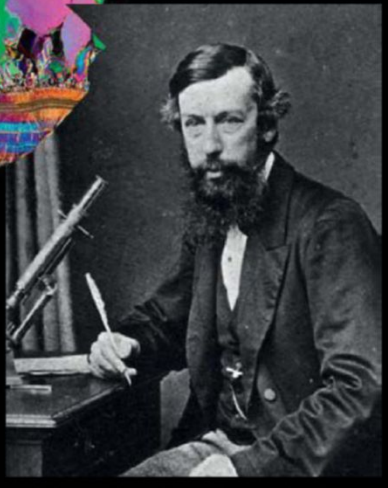
By slicing rock into extremely thin sections and studying them with a polarising microscope, Henry Sorby revolutionised the science of geology

Henry Sorby's application of the polarising microscope to examine rocks resulted from a chance meeting on a train with a Manchester surgeon who taught him to make sections of fossil wood, teeth and bones. It occurred to Sorby that a great deal might be learned by applying a similar method to the study of rocks. He made numerous thin sections by first grinding a slice of rock roughly, smoothing it on a lead plate with coarse emery, and finishing on a copper plate with fine emery. The thickness of 30 microns (millionths of a metre) that he achieved is still the standard used today, over 160 years later.

In 1851, Sorby published a paper describing this technique and the mineral content of a thin section of sandstone. Using a microscope fitted with polarised light, he determined that some of the particles were calcite, some were quartz and others agate, which would have been impossible using the old method of crushing rocks. Unfortunately, this new technique of examining rocks did not find favour among most geologists of the day and was ridiculed by many. It wasn't until the 1860s that the technique of using polarised light to identify minerals became established as an essential tool for the examination of rocks.



A polarised light micrograph of a thin section of agate mineral, reveals layers of chalcedony surrounded by quartz crystals



The geology pioneer: Henry Sorby

PHOTO: ALAMY X3, SCIENCE PHOTO LIBRARY X2, SCIENCE & SOCIETY, UNIVERSITY OF SHEFFIELD

one of the first books on fossils published in English, James Parkinson (who also identified Parkinson's disease), complained about the difficulty of writing about a science with no name.

Society success

Nevertheless, interest in geology was growing rapidly, due largely to the demand for coal, iron and other metals. In 1807 this led to the establishment of the world's first Geological Society in London. One objective was to identify where Britain's wealth lay underground and another was to sort out the geological nomenclature.

In every part of the country, the same rocks had different names, making it extremely difficult to know if two rocks were identical if they did not contain fossils; fossils are in fact found in only 15 per cent of rocks. To this end the Society's first President, George Greenough, invited people to send in geological information from their local areas. Over the next decade, maps, rocks and details about geology flooded in from all over the country. Such was the Society's success it had to move premises three times to accommodate all the material!

Progress during geology's golden age, the 1830s, was swift. By the 1840s all the geological periods from the Tertiary to the Cambrian had been identified and named, except for the Ordovician. A 'period' is a subdivision of geological time that enables cross-referencing of rocks and geological events from place to place. Periods are grouped into eras, and eras into eons. The younger periods posed few problems because they mostly contained large numbers of fossils, which enabled their chronology to be ordered quite easily. The older periods were more controversial, however. They contained fewer fossils so were harder to position accurately relative to each other. In addition, older rocks have often been deformed and overturned, making it more difficult to understand the original sequence.

In 1832, Henry Thomas De la Beche undertook a geological survey of Devon. This work eventually led to the establishment of the Geological Survey in 1835, but not before De

CAST OF CHARACTERS

The men who established an entirely new field of science: geology

Nicolas Steno (1638-1686) was born into a wealthy Lutheran family in Denmark. His study of geological processes culminated with his great work, *Prodromus*, now regarded as a masterpiece. Unfortunately, his conversion to Catholicism produced an intellectual conflict with his geological observations, and shortly after writing *Prodromus*, Steno lost interest in geology.

William Smith (1769-1839), English civil engineer and geologist, was called Strata Smith due to his discovery that strata can be traced across the country by correlating the suites of fossil they contain. He published the first geological map of the British Isles in 1815, representing the strata in different colours.

George Greenough (1778-1855), whose independent means facilitated his interest in rocks, was important in the development of British geology due to his organisational skills. In 1807 he became the first President of the Geological Society and can largely be credited for its rapid success.

Henry De la Beche (1796-1855), the son of a Jamaican plantation owner, was a gentleman geologist whose interest in economic geology led to the establishment of the Geological Survey in 1835, of which he was the first Director. He became embroiled in a bitter controversy with Roderick Murchison (1792-1871) over the geology of Devon.

Henry Sorby (1826-1908) was born near Sheffield. His early training in chemistry and mathematics influenced his approach to research. He made several observations of significance to geology and developed the technique of making thin sections of rocks and observing the minerals they contained under a polarising microscope. This transformed the classification of rocks.

TIMELINE

Our understanding of Britain's geology has taken centuries of investigation to classify rocks and their minerals

+3000BC

Prehistoric humans identify a number of rock types during their search for resources such as flints found in chalk, copper and tin ores for bronze, and clay for pottery.

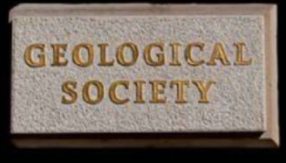
1669

Nicolas Steno develops the law of superposition, which states that sedimentary layers are deposited in sequence, with the oldest on the bottom and the youngest on the top.

1794

William Smith notices that each rock layer has a characteristic suite of fossils enabling him to correlate two strata containing the same suite of fossils, even though they are miles apart.

1807



The world's first Geological Society is founded in London. It collects material from all over the country, trying to collate the geological history of the British Isles.

1835

The British Geological Survey is formed, led by Henry De la Beche. For over 150 years its employees map the geology of the British Isles.

1851

Henry Sorby publishes a paper on how to make thin sections and identify minerals in rocks using a polarising microscope. This finally establishes a scientific method for classifying rocks.

PHOTO: GETTY X2, SCIENCE PHOTO LIBRARY X2, ALAMY, BRITISH GEOLOGICAL SURVEY

la Beche had suffered great public embarrassment. While he mapped the strata in Devon, his colleagues Roderick Murchison and Adam Sedgwick were similarly engaged in Wales, respectively establishing the Silurian and Cambrian systems. Everyone assumed that the rocks in Devon were around the same age as those in Wales. But in 1834, when De la Beche found Carboniferous fossils in coals embedded in the middle of rocks he thought were Silurian, he declared that William Smith's theory of ordering the rocks using the fossils they contained must be wrong. Murchison leapt to the attack even though he had never examined the Devonshire strata himself. This deeply offended De la Beche, who believed that the validity of field work should not be questioned on theoretical grounds.

When Murchison and Sedgwick examined the Devonshire rocks themselves in 1836, they found that De la Beche had made a mapping error. The coal deposits were in fact at the top of the Devonshire strata rather than in the middle, so they assumed the coal must lie at the bottom of the Carboniferous, sitting on the older Silurian rocks – what's known as an unconformity (see 'Need to know', right). De la Beche was publicly criticised and the fledgling Geological Survey was nearly brought to an untimely end. But the arguments didn't end there. De la Beche was forced to admit his error, but he insisted that there was no unconformity between the coal strata and the older Silurian rocks. To their discomfort, Murchison and Sedgwick could not identify an unconformity either and had to admit that there wasn't one.

The Devon conundrum

There followed much debate and extensive investigations ranging as far afield as Russia, where in 1840 Murchison discovered a layer similar to the coal found in Devon, positioned between well-defined Silurian and Carboniferous deposits. This finally put an end to what became known as the Great Devonian Controversy and led to the definition of a new period called the Devonian. It also led to a fundamental

NEED TO KNOW

You'll need these key terms to understand the history of geology

1 IGNEOUS ROCKS
These form when molten rock cools and solidifies, either on the Earth's surface, like basalt, or within the crust like granite.

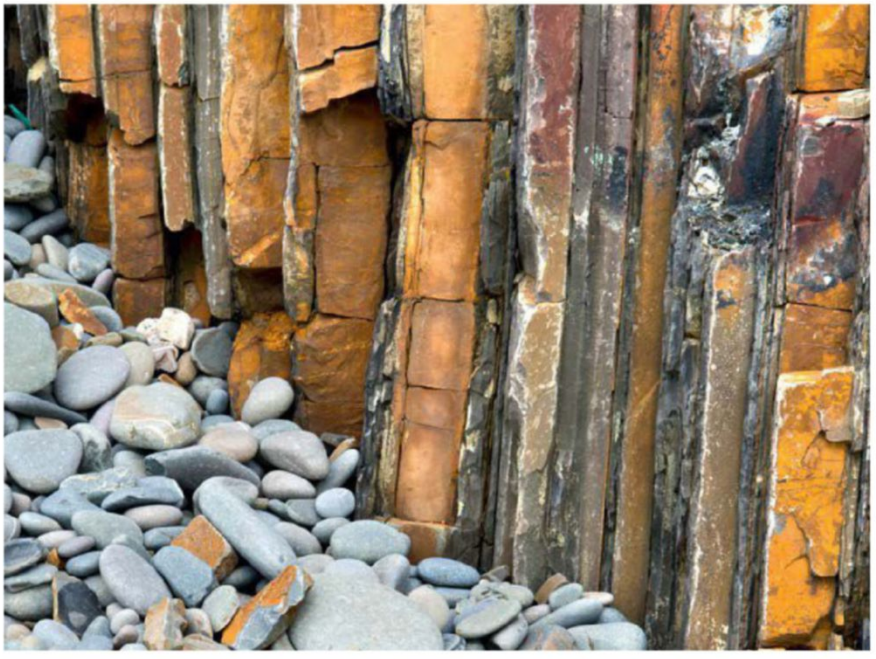
2 METAMORPHIC ROCKS
Pre-existing rocks that have been transformed by intense heat and pressure.

3 POLARISED LIGHT
This is where light that is normally scattered in all directions is restricted so that you can only see the waves that are vibrating in one direction.

4 POLARISING LIGHT MICROSCOPY
A technique that uses filters to configure the movement of polarised light waves, forcing their vibration in one direction.

5 SEDIMENTARY ROCKS
These form from the deposition, usually in water, of eroded material from other rocks.

6 UNCONFORMITY
This is a gap between two rock layers that represents a break in the geologic record, often of hundreds of millions of years.



Sedimentary rock at Sandymouth Bay in Cornwall shows distinct bands that enable geologists to identify the time period that the strata was formed

change in geological practice and the value of fossils as stratigraphic indicators was established beyond question. Fortunately, the Geological Survey survived this early trauma and De la Beche became its first Director. Both the Geological Society and the Geological Survey still exist today.

By the late 19th Century, geologists recognised that rocks were made up of individual minerals, and it was the size and composition of these minerals that determined the type of rock. There were three basic types – igneous, sedimentary and metamorphic – but as geological mapping became more refined, a more precise classification was required. It became necessary to identify which minerals were present and in what quantities. However, while it was possible to see minerals with the naked eye in rocks such as granite, other rocks such as basalts were harder to classify, because the minerals they contain are extremely small.

Until the 1860s, geologists would crush up rocks to a coarse powder and examine them under the microscope, but identifying minerals this way was rather crude, and it was very difficult to accurately measure the proportions. It was not until polarised light was applied to the study of minerals under the microscope that a systematic identification of rocks became possible (see 'The key discovery').

The first steps were taken by Henry Sorby, who prepared thin sections of minerals and fossil woods for microscopic investigation. A thin section, as the name suggests, is a polished slice of rock so thin that you can see through it. When placed between pieces of glass on a polarising microscope, each mineral in the rock slice displays different optical properties – mainly colour and shape – that can be used to identify it very accurately. This finally established a scientific method for classifying rocks and was to transform our ability to distinguish one rock from another.

The geology of the British Isles is renowned for its diversity. Rocks of almost all geological ages can be found and mapping them over the past two centuries was the single most important contribution to our understanding of our islands' geology. Then in the 1960s, development of the theory of plate tectonics began to unravel Britain's complex tectonic history. Over the past four billion years or so, as Britain wandered the globe, it accumulated a record of warm and cold seas, deserts, tropical swamps, giant rivers, glaciations, earthquakes, volcanic eruptions, continental collisions, and the evolution of life as preserved in its fossils. Our knowledge of that record has slowly accumulated, but even today we still don't comprehend it all.

DR CHERRY LEWIS is a geologist and the author of *The Dating Game: One Man's Search For The Age Of The Earth*

ULTIMATE TEST

TABLET TEST

Fancy buying one or upgrading your tablet in the coming new year? Joe Minihane checks out your options

The end of the laptop is nigh. Sony has sold off its iconic Vaio brand and Samsung has announced plans to stop selling its portable PCs in Europe. Windows is no longer a PC–only affair. The reason? Tablets. Gartner analysts reckon 2015 will see slates outsell laptops and desktops for the first time. But tablets aren't all the same. Here are the best ones to buy, whether you're a workaholic, gamer, traveller or on a budget.

PHOTO: THESECRETSTUDIO.NET

BEST FOR WORK

MICROSOFT
SURFACE PRO 3

Screen: 12 inches
Weight: 800g
RAM: from 4GB
Processor: 4th Gen Intel Core, 1.9GHz
Battery life: Up to 9 hours of web browsing

Microsoft reckons the Surface Pro 3 is "better than your laptop, better than your tablet". Marketing flim-flam aside, that's because this is really a bit of both. The 12-inch screen is huge compared to the likes of the iPad Air, but its high resolution makes it great for watching Netflix while the kids colonise the TV. Its lack of BBC iPlayer and Sky Go apps is a pain, although you can access these services via the web.

But really the Surface Pro 3 is all about productivity. Yes, you need to pay extra to access Microsoft Office, but once you do, this becomes the ultimate work tool. You can tweak spreadsheets and presentations using the stylus, which is more precise than podgy digits when it comes to crunching numbers.

And if you snag the excellent Type Cover, the Surface Pro 3 flips out into a proper laptop, meaning you can bash out emails and reports before folding the whole thing away into your backpack. What's more, the upcoming Windows 10 update will introduce one store for apps across all Microsoft kit, including phones, tablets and the Xbox.

Cost is an issue – the Type Cover alone comes with a huge price tag – but the Surface Pro 3 really does hit a sweet spot.

BEST FOR TRAVEL

APPLE IPAD MINI 2
WITH RETINA DISPLAY (WI-FI AND 4G)

Screen: 7.9 inches
Weight: 331g (Wi-Fi only model)
RAM: 1GB
Processor: Apple A7, 1.3GHz
Battery life: Up to 10 hours of web browsing

Steve Jobs once described seven-inch tablets as "tweeners". The late Apple CEO said smaller tablets were "dead on arrival" and couldn't compete with the more fulsome iPad. Admittedly the iPad Mini's display is a slightly more capacious 7.9 inches, but this trimmed-down Apple tablet is unquestionably its best.

Its size makes it the perfect travel tool: small enough to slip into hand luggage without weighing you down, large enough that you can whip it out and watch a film mid-flight without having to squint at the screen. The slick Retina Display really comes into its own here.

Of course, there are plenty of similar-sized alternatives. But what makes the iPad Mini stand out is the sheer breadth of apps available, plus its sharp design. iPlayer is a must for anyone who wants more than the smattering of second-rate sequels which pass for in-flight entertainment.

Use Newsstand for travel mags and iBooks to buy guides and books that would otherwise take up valuable luggage space. And remember you can get Google apps for iPad, too. The search giant's translation tools and maps are great additions, especially now that roaming fees worldwide are plummeting.

BEST FOR GAMING

NVIDIA
SHIELD

Screen: 8 inches
Weight: 390g
RAM: 2GB
Processor: NVIDIA Tegra K1, 2.2GHz, Quad-core
Battery life: Up to 10 hours of web browsing (5 hours of gaming)

Chip-maker NVIDIA has plenty of gaming nous and its GeForce graphics power the best gaming PCs out there. So it's no surprise that the super-powered Shield tablet is a cut above the rest when it comes to playing the latest titles.

Its speedy K1 chip is what sets it apart from bog-standard slates. This lightning-fast processor can handle the kind of graphical trickery usually reserved for the very best PCs, meaning that games look absolutely fantastic from the minute you fire them up.

For the best results, you'll need to find extra cash for a Shield controller, or get one as part of a bundle. This allows you to utilise the entire screen while gaming, which is a must if you're using NVIDIA's Gamestream service to pull games from your PC to your tablet. The latter is a tricky proposition if you don't have a truly stable network connection, so it's best to stick to streaming in your home rather than over a 4G connection.

What is far more exciting is the ability to use the NVIDIA Shield device with your television via HDMI. Apple's failure to bring iOS games to the Apple TV means NVIDIA is really out on its own here. Simply tap the Console Mode app on the home screen and you're away.

BEST FOR BUDGETS

TESCO
HUDL 2

Screen: 8.3 inches
Weight: 410g
RAM: 2GB
Processor speed: Intel Atom, 1.83GHz, Quad-core
Battery life: Up to 8 hours of web browsing

The unlikely success of the Tesco Hudl was one of 2013's biggest tech surprises. The Hudl's successor, Hudl 2, is better in every way. Its screen is an inch bigger and now supports Full HD, so you can stream movies in high definition over the supermarket's own Blinkbox service. Blinkbox also features loads of books and music to keep you entertained.

Parental controls are seriously impressive, with a native app built in conjunction with The Parent Zone website, which allows you to set up as many as seven profiles. These can be tweaked to prevent access to certain apps, while time limits are also an option. It's a brilliantly realised tool and one which puts more expensive tablets to shame. At 410g, it may be a tad on the weighty side for travel, but it comes in a choice of eight bright colours. Chuck in full access to all of Google's services – including the Play Store and its enormous selection of apps – plus the latest Android software, and it's hard to see why you'd want to splash out on a pricier model.

Of course, the price is the big draw as it costs a lot less than an entry-level iPad Mini 2. That extra lump of cash could make a big dent in your budget.

Time Out

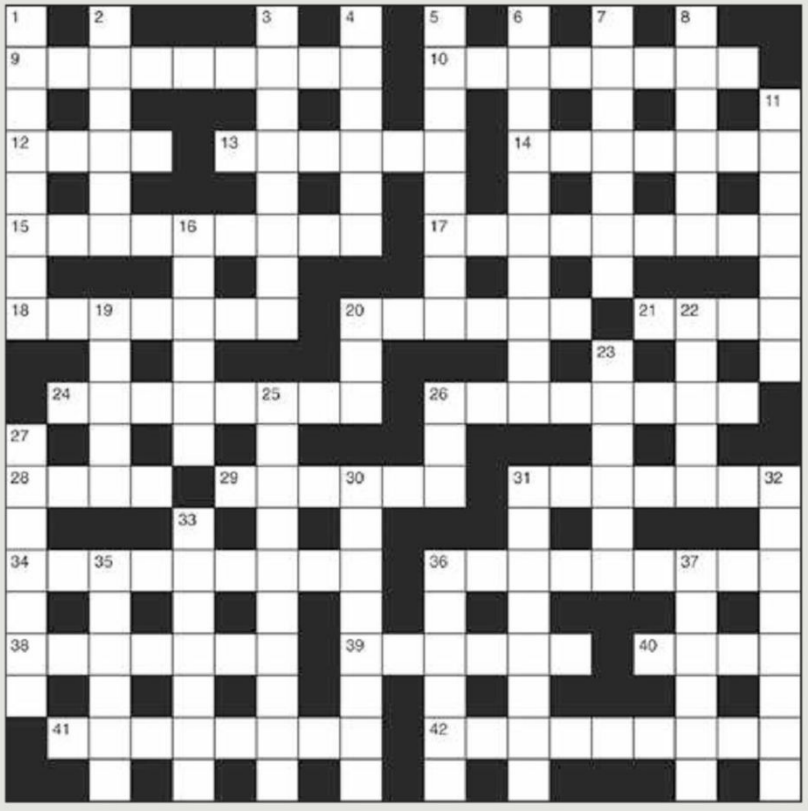
Crossword No.171

ACROSS

9 Unoriginal, having to throw one fossil (9)
10 Calcium turns old urn into a pot (8)
12 Repeat in the choir (4)
13 Seafood provides strength, we hear (6)
14 European doctor – lost soul – finds blockage (7)
15 Radioactive ingredient put menu in trouble (9)
17 Bankrupt at home, getting thinner (9)
18 Not worried about New Age capacity (7)
20 Dogtooth (6)
21 Old soldiers get the sign (4)
24 Bishop finds Cupid is wrong on a couple of points (8)
26 Epic mass performed as a way of avoiding reality (8)
28 Miracle, finding key inside (4)
29 German upsets Poles – that's the truth (6)
31 Fellow cultivates lilac in a certain shape (7)
34 Mineral and elm phobia developed (9)
36 Fingernail broke preparing heart remedy (9)
38 Old notes on one place at the back of the head (7)
39 Old Indonesian turned native (6)
40 Witches' irritation (4)
41 Capital party – performing dance? (8)
42 Mood is gloomy about enema, oddly (9)

DOWN

1 Tree then integrated into local network (8)
2 Piece of the clergy (6)
3 Statistic about trendy statuette (8)
4 Planes, by morning, become expendable matter (6)
5 After second visit I find no new onion (8)
6 Policeman threw coins very fast (10)
7 Occasional party is eccentric (7)
8 Miner reaches no conclusion on pet (6)
11 Dye compound, that is, takes in material (7)
16 Unionist artist confuses sun and planet (6)
19 A vine turned green (5)
20 Payment method for fish (3)
22 Frenchman thus takes turn at art form (5)
23 Fruit on time for program (6)
25 Support putting gold into new relationship (10)
26 Point to the Spanish swimmer (3)
27 Organise conga to get in shape (7)
30 Quiet chap gets an alternative book with child (8)
31 Reprimand for activity in field (4,4)
32 Some cattle yearn to get a bit of brass (8)
33 Exposure to radio drama (7)
35 Exercise can include carbon and E440(a) (6)
36 Part of area of high ground (6)
37 A great deal to charge for a preparation (6)



SOLUTION TO CROSSWORD 168

Q&A

YOUR QUESTIONS ANSWERED

BY OUR EXPERT PANEL

SUSAN BLACKMORE
Susan is a visiting psychology professor at the University of Plymouth. Her books include *The Meme Machine*

DR ALASTAIR GUNN
Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester

ROBERT MATTHEWS
After studying physics at Oxford, Robert became a science writer. He's a visiting reader in science at Aston University

GARETH MITCHELL
Starting out as a broadcast engineer, Gareth now writes and presents *Digital Planet* on the BBC World Service

LUIS VILLAZON
Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

editorial-bbcknowledge@regentmedia.sg

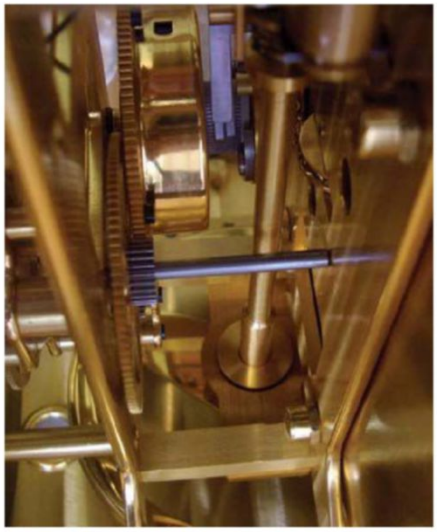
Q How does underwater welding work?

A Metal, water and hundreds of amps of current is not a happy combination, and much underwater welding is performed with the welder working in a diving chamber. Even so, wet welding is possible. Special waterproof electrodes protect the diver from the current, while the heat forms bubbles that remove the water from the site of the weld. **RM**

Down in the water deep and low, where all the diving welders go...

PHOTO: BAE SYSTEMS

What's the longest a 'perpetual motion' machine has run so far?



The Beverly Clock has run *almost* constantly for 150 years

The idea of a machine that keeps running forever has been around for centuries, with even Leonardo da Vinci and Robert Boyle coming up with proposals. None have proved 'perpetual', however, as energy loss due to effects like air resistance and friction eventually brings them all to a halt.

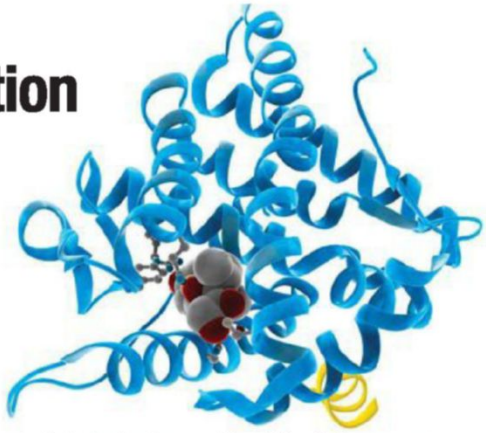
Arguably the closest we have to a perpetual motion machine is the Beverly Clock in the Department of Physics of the University of Otago, New Zealand. Built in 1864, it's powered by pressure and temperature changes in the surrounding air. As these owe their origin to the Sun's energy and the rotation of the Earth, they could in theory keep the clock going for millions of years. In reality, it has paused a few times when the atmospheric conditions weren't quite right, but it has so far always started up again. **RM**

In Numbers

$600m

Estimated cost of fighting the Ebola outbreak in western Africa, according to figures from the World Health Organization

How do anti-rejection drugs work?



Anti-rejection drugs work by tricking the immune system

Organ rejection happens when a transplanted organ is attacked by your immune system. Anti-rejection drugs interfere with some aspect of this system, and there are three main kinds.

Glucocorticoids are steroid hormones that are produced naturally in the body as part of a mechanism that prevents inflammation from getting out of hand. Adding extra glucocorticoids turns down the thermostat on the body's immune system. Monoclonal antibodies bind to proteins on the surface of T cells (a type of white blood cell). T cells are the worker ants of the immune system and certain monoclonal antibodies will bind to and deactivate them. Finally, there are the drugs that target messenger chemicals in the immune system. Ciclosporin is the best-known of these and works by preventing the production of interleukin 2, a molecule that is used to flag which cells are 'foreign'. **LV**

What's the most distant observed galaxy?

An artist's impression of Z8_GND_5296. Best start saving those air miles...

Currently, the most distant (and hence oldest) galaxy known to astronomers is called z8_GND_5296. It was discovered in 2013 using a combination of data from the Hubble Space Telescope and the WM Keck Observatory in Hawaii. Astronomers use a measurement called redshift to determine distance. This galaxy has a redshift of 7.51 – the highest yet discovered – and is an estimated 13.1 billion light-years away. This means we are seeing z8_GND_5296 as it was only 700 million years after the Big Bang. Since the Universe has expanded significantly in that time, z8_GND_5296 will now lie 30 billion light-years from Earth. Not only is z8_GND_5296 a record holder, it is also an oddity. While normal galaxies like our own Milky Way may produce a couple of new stars each year, z8_GND_5296 has a star-formation rate 150 times greater. The observations have suggested that even more distant galaxies may be hidden in the fog of neutral hydrogen gas prevalent in the early Universe. **AG**

PHOTO: STEVE JURVETSON/FLICKR, SCIENCE PHOTO LIBRARY, THINKSTOCK X3, NASA/HUBBLE

Q&A

In Numbers

5.5km

is the height of Martian mountain Aeolis Mons. NASA's Curiosity rover reached the mountain – its primary destination - on 11 September

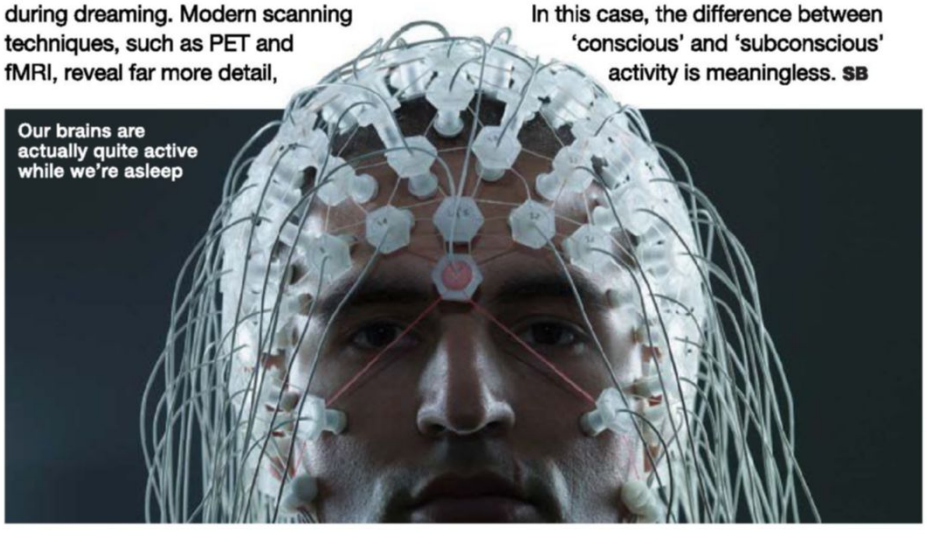
Is the right side of your brain really more creative?

A No. At least, not in the popular sense that creative people are more 'right-brained' than logical or analytical people are: a study that scanned the brains of over 1,000 people found no such differences. It is true that different brain areas are specialised for different tasks, including vision, hearing, touch and the control of movements. And the main language areas are in the left hemisphere in 95 per cent of right-handers. But both hemispheres work together in almost everything we do and creativity is a whole-brain process. Painters and sculptors may draw on mathematical and logical ideas as well as visual imagery and words, just as scientists inventing a new theory may do the reverse. **SB**

Contrary to popular belief, most activities use both sides of the brain

Can subconscious brain activity be measured?

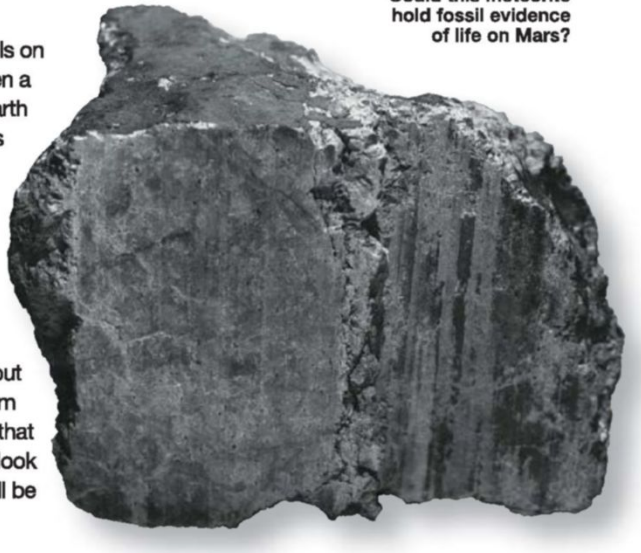
A Yes, easily. The problem is not measuring brain activity but knowing what the terms conscious, subconscious or unconscious mean. In the 1950s the EEG (electroencephalogram) was invented, using electrodes on the scalp that revealed waves of activity across the surface. As technology improved, more 'brain waves' were discovered but with no hint that some were conscious and others not. An early, surprising finding was the amount of activity during sleep, and especially during dreaming. Modern scanning techniques, such as PET and fMRI, reveal far more detail, with increasingly accurate localisation. But how can we tell whether any activity is conscious or not? Many researchers are seeking the 'neural correlates of consciousness'; the special patterns or locations associated with conscious, rather than non-conscious activity. Although this seems to be the Holy Grail of consciousness studies, another possibility is that consciousness is not a property of brain activity at all, but something we attribute to events after they happen. In this case, the difference between 'conscious' and 'subconscious' activity is meaningless. **SB**



Our brains are actually quite active while we're asleep

Could fossils survive a meteorite impact?

A Yes. In fact, there might be fossils on the Moon that arrived that way. When a sufficiently large meteorite strikes Earth at the right angle, some of the debris is ejected fast enough to escape Earth's gravity, and is captured by the Moon. Kent University researchers found this year that some fossils could survive both the original impact of the Earth meteorite and then the second one when the debris struck the Moon – but only if they were smaller than 0.04mm across. Nevertheless, this suggests that the Moon could be a good place to look for fossilised plankton, since they will be much better preserved there. **LV**



Could this meteorite hold fossil evidence of life on Mars?

PHOTO: CORBIS, NASA, THINKSTOCK X3, INGO ARNDT/MINDEN PICTURES/FLPA

Monarch butterflies congregate to take on water in Michoacan, Mexico

Why don't butterflies fly in straight lines?

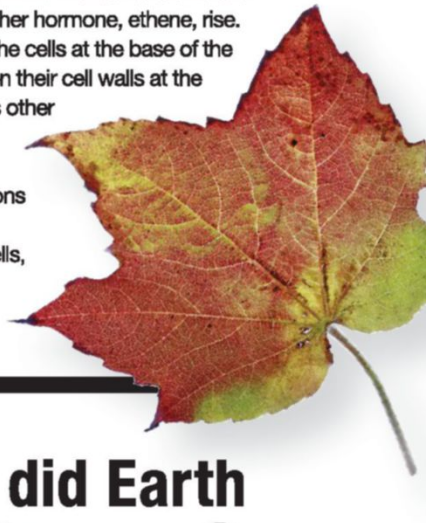
A Butterflies and moths use their wings for many purposes: for flight, as mobile billboards to advertise how poisonous they are, and to create camouflage patterns. So you would expect them to be less adept fliers than insects that have optimised their wing design purely for aerodynamics. But the butterfly's erratic flight is actually an evolutionary tactic that makes it harder for any would-be predators to predict the insect's flightpath. The more poisonous butterflies don't need to carry out these evasive manoeuvres, and as a result these species tend to fly much straighter.

Fluid dynamics simulations that were carried out at Kyoto University in Japan last year showed that butterflies achieve their trademark swoops and tumbles by generating a lot of extra turbulence with each wing beat. And high-speed photography studies undertaken at Johns Hopkins University in Baltimore, US, reveal that they also constantly adjust their centre of gravity by shifting the position of their body and wings.

Monarch butterflies are so good at this that they can effect a 90-degree turn in less than a single body-length. **LV**

What makes deciduous plants start to lose their leaves in autumn?

A Deciduous trees shed their leaves as an active process that evolved to conserve resources and protect the tree from being blown over in the windier winter months. The process is controlled by the plant hormone auxin. As light levels and temperatures drop, the flow of auxin to the leaves slows and levels of another hormone, ethene, rise. This signals the cells at the base of the leaf to weaken their cell walls at the same time as other cells expand to break the connections between the weakened cells, like tearing perforated paper. **LV**



How did Earth get its name?

A Each language has its own name for our planet but they all have one thing in common. Each is derived from a word meaning 'ground' or 'soil' (or sometimes 'universe' or 'creation').

For example, the modern English word 'Earth' derives from the Germanic 'erde', meaning 'ground'. The roots of such words all date from a time when humankind was unaware that Earth is actually a planet. They merely signified the ground beneath our feet, and were adopted for the planet later on. **AG**

Our planet shares its name with the ground we walk on in nearly all languages

Q&A

TOP TEN
BIGGEST SPIDERS
BY LEG SPAN

1. Giant Huntsman
Length: Up to 30cm
Distribution: Caves in Laos. Other huntsman species are found worldwide

2. Goliath Birdeater
Length: Up to 28cm
Distribution: Upland rainforest regions of northern South America

3. Brazilian Giant Tawny Red
Length: Up to 26cm
Distribution: Tropical South America

4. Brazilian Salmon Pink Birdeater
Length: Up to 25cm
Distribution: Atlantic Forest, Brazil

5. Purple Bloom Birdeater
Length: Up to 22cm
Distribution: Moist forest areas of Colombia

6. Poecilotheria rajaei
Length: Up to 20cm
Distribution: Sri Lanka and parts of India

7. King Baboon Spider
Length: Up to 20cm
Distribution: Most of east Africa, especially Kenya and Tanzania

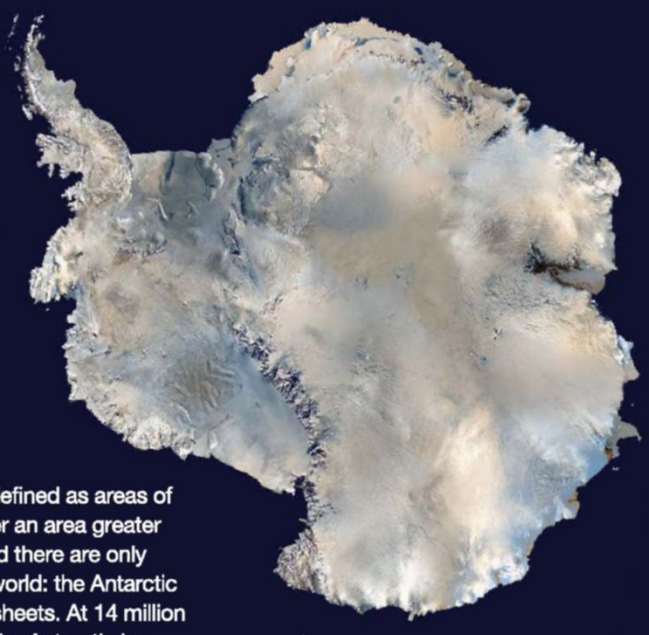
8. Golden Silk Orb-weavers
Length: Up to 16cm
Distribution: Australia, Asia, Africa, the Americas

9. Brazilian Wandering Spider
Length: Up to 15cm
Distribution: Forests of Central and South America

10. Cerbalus aravensis
Length: Up to 14cm
Distribution: Sand dunes in Israel and Jordan

PHOTO:MICKEY SAMUNI-BLANK/WIKI, RANIL NANAYAKKARA/FLICKR, PETRA & WILFRIED/FLCKR, JOSE LUIS BARTHELD, ANDREAS KAY, VLADEB/FLICKR, J&T REPTILES, STEVE SMITH/FLICKR, TJ PETROWSKI/FLICKR

Q What is the biggest ice sheet in the world?



A Ice sheets are defined as areas of glacier ice that cover an area greater than 50,000km², and there are only two of them in the world: the Antarctic and Greenland ice sheets. At 14 million square kilometres, the Antarctic ice sheet is by far the biggest – eight times larger than Greenland's. **LV**

The Antarctic ice sheet is the world's largest by a huge margin

Q Do bats get confused by other bats' 'sonar'?

Why find your own way around when you can get a neighbour to do it for you?

A Some bat species have a wide repertoire of available sound frequencies, so the chances of another bat happening to call on the same frequency within earshot are quite low. The Brazilian free-tailed bat will, however, actively switch frequencies if another nearby bat is using a frequency within 3kHz of its own.

But research at the University of Maryland has shown that bats can actually use the echolocation calls of other bats to navigate by eavesdropping. Big brown bats will sometimes stop calling altogether if they are flying close enough to another bat, and just listen for the echo from their neighbour's calls. **LV**

Q Is it possible to remember being in the womb?

A Many people claim they can, or that their toddlers can, but it is doubtful that these are genuine memories. Claims may be based on children imagining what it would be like, or being cued by adults. Most adults can remember events only as far back as the age of three or four. Young children often remember further back, but these early memories generally fade as they grow older.

This is what we should expect from knowing that the limbic system, which is heavily involved in memory, is not fully developed at birth, and that the whole brain changes rapidly in the early years. This is not to say that events in the womb have no effect: there is some evidence that music and voices heard before birth can influence your later preferences. But this is not the same thing as actually remembering life in the womb. **SB**

Q Are disposable nappies more harmful to the environment than reusable ones?

A Mostly. Eight million disposables end up in UK landfill sites every day. We don't know exactly how long they take to biodegrade, but it's likely to be more than 100 years. This means every nappy that's ever been thrown away is still there, and potentially leaking nasty chemicals into the groundwater. But if you compare the carbon footprint of manufacturing disposables with the energy used to manufacture and launder reusable ones, the picture is less clear. A 2008 study by the Environment Agency concluded that washable nappies are actually responsible for 3 per cent higher CO_2 emissions than disposables, per child. But these figures assume that 25 per cent of washable nappies will be dried in a tumble drier. If you dry all your nappies on the line, the balance switches and reusable nappies produce 13 per cent less CO_2 emissions than disposables. **LV**

Q Could there ever be tree-less paper?

The mainstay of a panda's diet could also be used to make paper

A There already is. More eco-friendly materials are increasingly used for paper production, including bamboo, banana husks and hemp (the main source of paper in the 19th Century). More esoteric alternatives include 'rock paper' made from ground-up minerals and a non-toxic chemical binder, which also needs less ink for printing. **LV**

Q What are the most popular smartphone apps in the world?

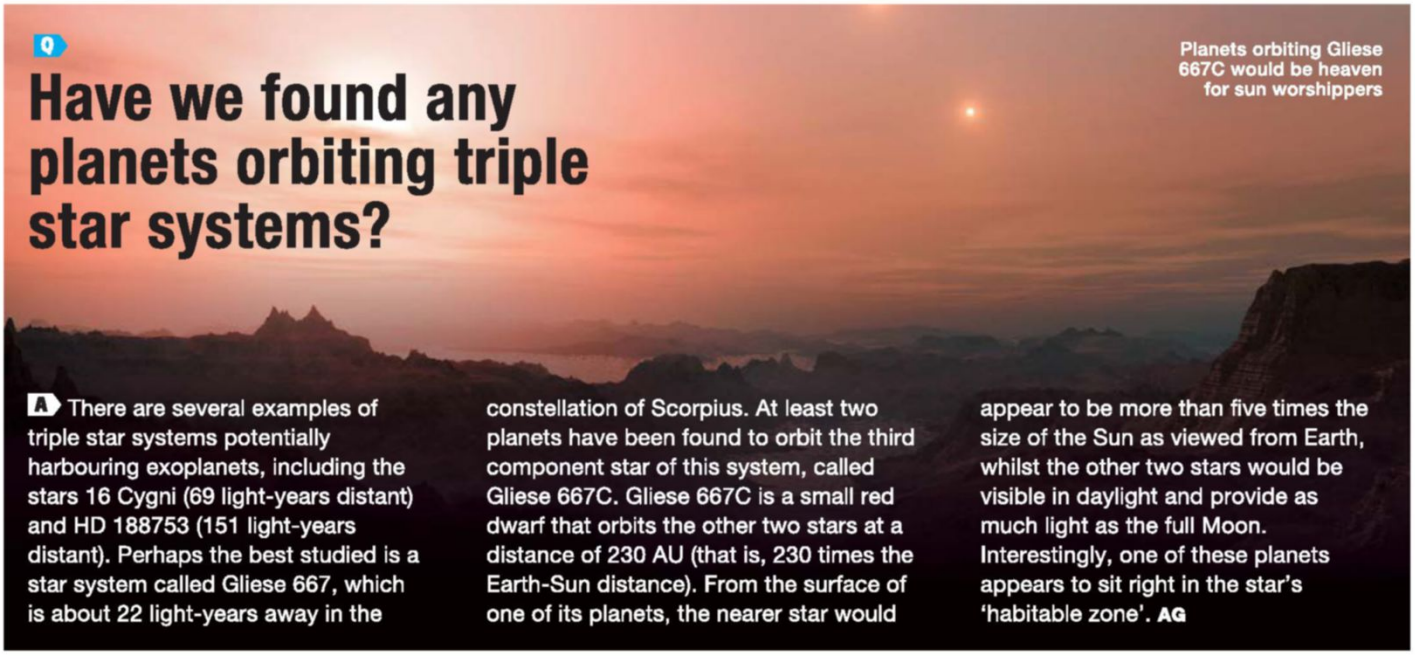
A The most recent figures I have are from 2013 by the analysts Global Web Index. At the time, there were 970 million smartphone users worldwide. Google Maps is the most popular app of all, followed by Facebook. At number five is Wei Xin. Never heard of it? It's a free instant voice messaging app and it's massive in China. Dominating in such a large smartphone market, Wei Xin is in the global top five despite only being used in China, Malaysia and Hong Kong. **GM**

Outside China, Wei Xin is known as WeChat

PHOTO: NASA, SCIENCE PHOTO LIBRARY, CORBIS, GETTY, FLPA

Q&A

Have we found any planets orbiting triple star systems?

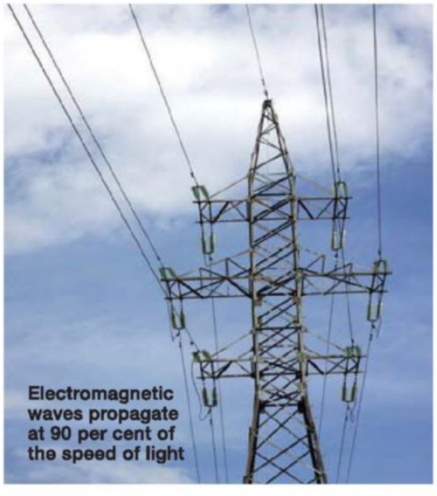


Planets orbiting Gliese 667C would be heaven for sun worshippers

A There are several examples of triple star systems potentially harbouring exoplanets, including the stars 16 Cygni (69 light-years distant) and HD 188753 (151 light-years distant). Perhaps the best studied is a star system called Gliese 667, which is about 22 light-years away in the constellation of Scorpius. At least two planets have been found to orbit the third component star of this system, called Gliese 667C. Gliese 667C is a small red dwarf that orbits the other two stars at a distance of 230 AU (that is, 230 times the Earth-Sun distance). From the surface of one of its planets, the nearer star would appear to be more than five times the size of the Sun as viewed from Earth, whilst the other two stars would be visible in daylight and provide as much light as the full Moon. Interestingly, one of these planets appears to sit right in the star's 'habitable zone'. **AG**

How fast does electricity flow?

A Drift velocity, the average speed at which electrons travel in a conductor when subjected to an electric field, is about 1mm per second. It's the electromagnetic wave rippling through the electrons that propagates at close to the speed of light. The dimensions of the wire and electrical properties like its inductance affect the exact propagation speed, but usually it will be around 90 per cent of the speed of light – about 270,000 km/s. **GM**



Electromagnetic waves propagate at 90 per cent of the speed of light

Secondary smoking is bad for insects, too

How do insecticides kill insects?

A Most insecticides are nerve agents that cause uncontrolled trembling or paralysis. These are toxic to other animals, too – organophosphate insecticides like DDT work the same way as chemical weapons like sarin and VX. Other insecticides work by mimicking insect hormones to prevent larvae from turning into adults, or to stop them from making the chitin they need for their exoskeleton. Some are synthetic versions of chemicals that plants make to discourage insects: neonicotinoids are based on nicotine from tobacco plants, for example. **LV**

PHOTO: ESO, THINKSTOCK X2, CORBIS, GETTY, SCIENCE PHOTO LIBRARY

Q

Are my files safe if I store them in the cloud?

A No file is 100 per cent safe, whether in the cloud or on your desktop. In the cloud, your files could be hacked, intercepted or lost. Even if the cloud service provider is watertight, someone might be eavesdropping on your web connection when you access your files, or stealing your password with a key logger.

The cloud services I use have built their businesses on securing, encrypting and storing data. I trust them more than I trust myself to keep my files safe. But before I sign up to any service, I check its data protection and privacy policies. Most cloud providers forbid their staff from accessing user content directly, though they may look at metadata such as file names, dates created, file size or location, and your files may be stored in jurisdictions that require your provider to decrypt files for law enforcement.

If that bothers you, then you should probably stay out of the cloud and just be careful with your own machine. **GM**

Cloud servers: not good for storing embarrassing pics

Q

How many nerves are there in the human brain?

A There are about 86 billion nerve cells, or neurones, in a human brain. This number was arrived at in 2009 at Rio de Janeiro University, by taking four adult human brains and dissolving the cell membranes to turn the brain into a cellular soup. Researchers could then count the cell nuclei in a small sample under a microscope and scale the numbers up. **LV**

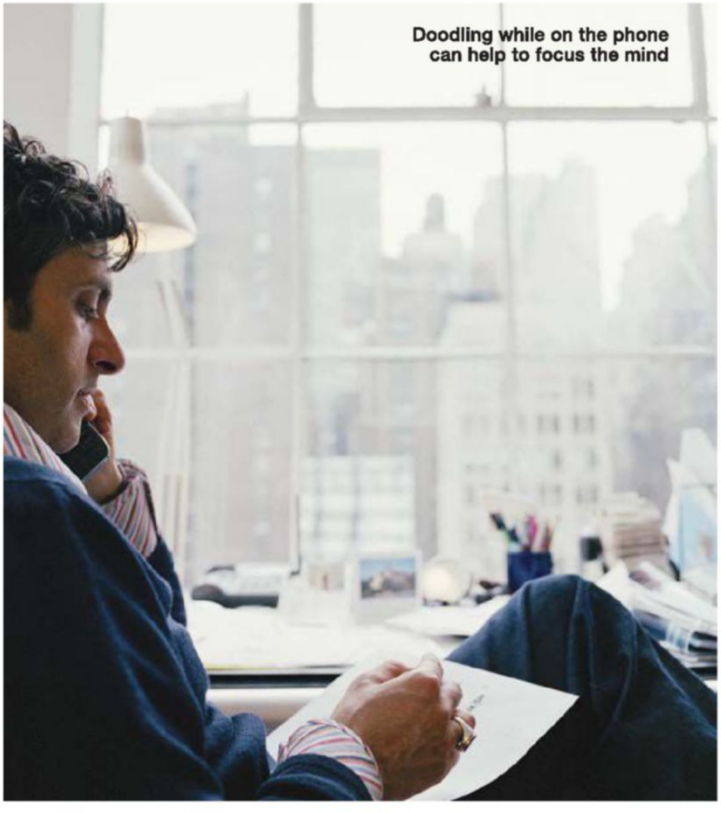
Q

Why do people doodle or pace up and down while on the phone?

A Sometimes doodling, pacing, scratching or fiddling with objects can be what are known as 'displacement activities'. This may be because the call is unwanted, makes us anxious, or because we want to get on with something else.

We should also remember that in natural, face-to-face conversations we typically move a lot, making hand gestures and using our whole body to communicate what we are trying to say. Being deprived of this visual communication channel can be frustrating, and that frustration can lead to unrelated actions, in much the same way that caged animals pace up and down behind bars or that cats suddenly start washing for no good reason.

In other cases the doodling or pacing may function as an aid to concentration. Some people find it easier to think, and not get distracted, if they are walking up and down. Others find that doodling can be creative, helping them to develop their ideas as they speak or even resulting in new ideas. **SB**



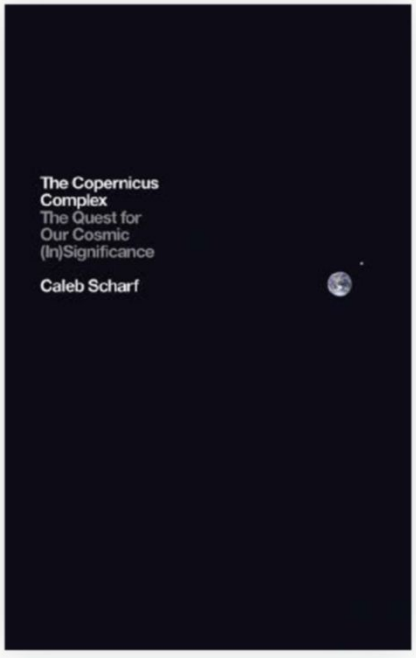
Doodling while on the phone can help to focus the mind

H Hardback P Paperback

How We Learn

The Quest For Our Cosmic (In)Significance

Caleb Scharf
Allen Lane H



One question above all others towers over us when we contemplate the Universe: "are we alone?" It's been the subject of intense debate for centuries. We used to think we were at the centre of the entire Universe, with the Sun, the planets and the stars revolving around us. That changed when Copernicus correctly placed the Sun at the centre of the Solar System, and it was realised that the stars were other suns. Suddenly, Earth was relegated to being just another planet around just another star.

In his latest book, astrophysicist Caleb Scharf suggests we're still feeling the hangover from this wrench in our understanding. In the intervening centuries, the Copernican principle has extended our mediocrity beyond the Solar System, stating that we're not in a special position in the Universe either. But, says Scharf, this has taken a stranglehold on our thinking. So *The Copernicus Complex* is a manifesto for an update in our thinking, in light of what we've been finding out about stars, life and other planets in the last few decades.

Take the search for exoplanets. Many of the early planet hunters expected to uncover carbon copies of our own Solar System – after all, we're not special. Yet the truth exploded that notion. There are giant, gassy planets orbiting astonishingly close to their parent stars, planets circling multiple stars, and an abundance of super-Earths – giant, rocky worlds for which we have no Solar System equivalent. It's also possible that we live at a special time in the Universe's history. In one sobering passage, we're informed that star (and planet) formation is happening at a rate that's just three per cent of what it was billions of years ago. Perhaps we're lucky to have sprung up when we did.

"Early planet hunters expected to uncover carbon copies of our own Solar System"

Scharf serves up a well-constructed argument, seamlessly flitting between deep philosophy, the latest astronomical findings and good old-fashioned storytelling. A particular highlight is when he recalls standing atop a Chilean mountain, gazing up at the boundless sky and contemplating the very origins of life.

In truth, there is nothing really new here. But if you're looking for an entertaining and well-written introduction to the latest ideas about where we come from and whether we're alone, this is a great place to start.

COLIN STUART is an astronomer and co-author of *The Big Questions In Science*

MEET THE AUTHOR

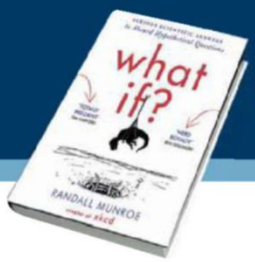
Caleb Scharf

What have exoplanets taught us about our own place in the cosmos? We've now detected evidence of over 4,000 potential exoplanets. On the one hand, this tells us that planets are incredibly abundant. But at the same time, we find that our Solar System is in a slightly unusual club.

For example, the orbits of the planets in our Solar System are more circular than in many systems, and our system doesn't contain some of the more abundant planet types such as super-Earths. If you put all the characteristics together, it looks like we live in a one-in-a-hundred kind of place. But we don't know whether this is related to the existence of life here.

Now we have an idea of some of the conditions needed for life, can we look for those conditions elsewhere? Absolutely. Here on Earth, biology has put a big fingerprint on the planet – it has affected the chemistry of the atmosphere, the surface environment, and the way the planet responds to seasonal changes. So we can look out for these 'biosignatures' on exoplanets.

So what was your conclusion after writing the book: is the Earth special? I think we may well be unique, but not exceptional. There could be lots of other planets out there with lots of life, some of which might be equally complex and sophisticated – but just very different. This is a way to reconcile the idea of cosmic mediocrity with the evidence that there are special things about the Earth. There may be lots of equally special places out there.



What If?

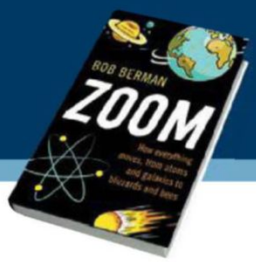
Serious Scientific Answers To Absurd Hypothetical Questions

Randall Munroe
John Murray (H)

In geek circles, webcomic XKCD is the epitome of cool. Now, creator and ex-NASA roboticist Randall Munroe turns his attention to (sometimes weird) questions posed by XKCD readers, such as 'If we all disappeared, how long before the last light went out?' and 'From what height could you cook a steak just by dropping it?'

Munroe lets his imagination run wild, taking us on a fantastic journey of thought experiments and poignant reflections through the lenses of physics, maths, biology, history and humanity. Collecting the best of his weekly blog, each answer is a treat packed with facts, logic, wild (yet rational) speculation, wry nerd humour and stick figure cartoons. A tour around Munroe's brain takes even the most oft-heard of questions - "What would happen if all humans jumped at the same time?", "What if I have just one soulmate?" – in surprising directions. Yet what shines through most is the author's incredible curiosity about the world and his ability to spin a fine yarn around it. It's like a trip up the scientific Amazon with the Indiana Jones of knowledge.

MUN-KEAT LOOI is a science writer and co-author of *Big Questions In Science*



Zoom!

How Everything Moves, From Atoms And Galaxies To Blizzards And Bees

Bob Berman
Oneworld (P)

From the atoms around us vibrating trillions of times a second to the distant galaxies that whoosh 150,000 miles farther away in a heartbeat – everything, it seems, is on the move. In *Zoom*, US writer Bob Berman takes us on a journey to explain how the world works, from the formation of sand dunes to the majestic movement of the aurora borealis.

Berman interweaves a formidable number of facts through the book that light up every page. Bamboo can grow at 39 inches a day; an empty mayonnaise jar contains enough energy to boil away the Pacific Ocean; some types of bacteria can travel 100 times their own body length in a second. It all adds up to an entertaining read, leaving you in no doubt about how incredible life and the Universe we live in really are.

Indeed, there seems to be little untouched, with Berman closing with how quantum entanglement – dubbed "spooky action at a distance" by Einstein – implies that something, whatever it is, can even travel in zero time. As Berman himself puts it: "Everything moves; it has always moved; it is its nature to move."

MICHAEL BANKS is the news editor of the journal *Physics World*

A Buzz In The Meadow

Walter Mischel
Jonathan Cape (H)

This is ostensibly the story of how Goulson, one of Britain's leading entomologists, bought a ruined French farm for a song and set about renovating it and observing the wildlife of its beautiful meadow. Power tools catch fire due to idiosyncratic wiring, much wine and cheese is consumed, and there's a narrow escape when hunters pepper the author with lead shot – all pretty familiar stuff. What make this a worthy sequel to *A Sting In The Tale* (Goulson's surprise bestseller about bumblebees) are the insights we get into the secret lives of the insects, plants and other species found on the farm's 33 acres. There's a lot of sex – for instance, we learn about a bizarre plant disease called campion smut, in which a fungus makes flowers change sex, and about the phenomenal fecundity of male deathwatch beetles, who in the act of ejaculation transfer up to 20 per cent of their bodyweight to the female in one go.

Goulson brings obscure biological experiments to life and turns complex ecology into a real page-turner, ending with 65 sobering pages that highlight some of the damage we are collectively wreaking on the natural world.

BEN HOARE is features editor of *BBC Wildlife Magazine*

How We Got To Now

The History And Power Of Great Ideas

Steven Johnson
Particular Books (H)

We're constantly told that innovation is vital to our future health, wealth and happiness, but how does it come about? Is it inspiration, perspiration or something more complex? Steven Johnson tackles this question by looking at six innovations that have shaped our modern world: glass, refrigeration, audio technology, sanitation, time measurement and lighting.

As he shows, a lot of the neat and tidy stories about how innovation happens are just plain wrong. For example, lots of inventors beat Edison to the design of the light bulb – he was just the first to make it really good. Johnson also highlights how one innovation often triggers many more. The invention of printing sparked increased demand for spectacles, which in turn led lens-makers to the development of the telescope and the microscope.

While he has an ear for a great anecdote, Johnson's writing style veers between the academic and the populist, and some of his analysis is less than lucid. Still, by the end, you'll almost certainly have learned something new.

ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham

The Last Word

From homeopathy to climate change, some issues can't help but cause the 'red mist'

Anyone can start a fight in a pub; just shove your way to the bar, spill a few pints on the way, then ignore the complaints. Getting people to kick off at a genteel tea-party is a bit harder - but it can be done. Just pour the tea for everyone, ask if they want milk in before or after - then put the tea in first anyway, and tell them not to be so daft. Cue complaints – or worse – when victims insist milk always be put in first. "It stops the tea tasting too bitter," they'll say, or "It conforms to BS 6008, the British Standard for making tea." Yes, really.

Then cue the other lot, explaining how it makes no sense to add milk until you've seen how strong the tea is. That was George Orwell's conclusion in his polemic on the subject, published in 1946. He knew he was asking for trouble. When I did a piece on the science of tea-making for a newspaper, the heaps of mail I got showed nothing had changed 50 years later.

Ever since, I have been perplexed by why some issues cause the 'red mist' to descend, while others leave people unmoved. There's no telling what it might be. Having facts to argue over seems irrelevant. It's been proven beyond all reasonable doubt that there's no link between the MMR vaccine and autism, yet it's a brave person who'll sound off on the subject at the local antenatal group.

Having a scientific training doesn't prevent the red mist effect either. One newspaper recently ran a piece about the notoriously provocative subject of animal experimentation. The resulting comment section featured the usual nutters from both sides of the debate – along with professional scientists hurling abuse at one another.

"There's a whole host of issues capable of causing even the most rational of people to descend into fury"

It doesn't even have to be about anything important. Take the case of what dries the clothes in a spin-dryer. It's centrifugal force, right? Whoah – you might think so, but as any science writer knows, using the C-word to explain what's happening will unleash a torrent of outrage from retired physics teachers; indeed, I'll probably get rebuked just for saying it's not a very important issue.

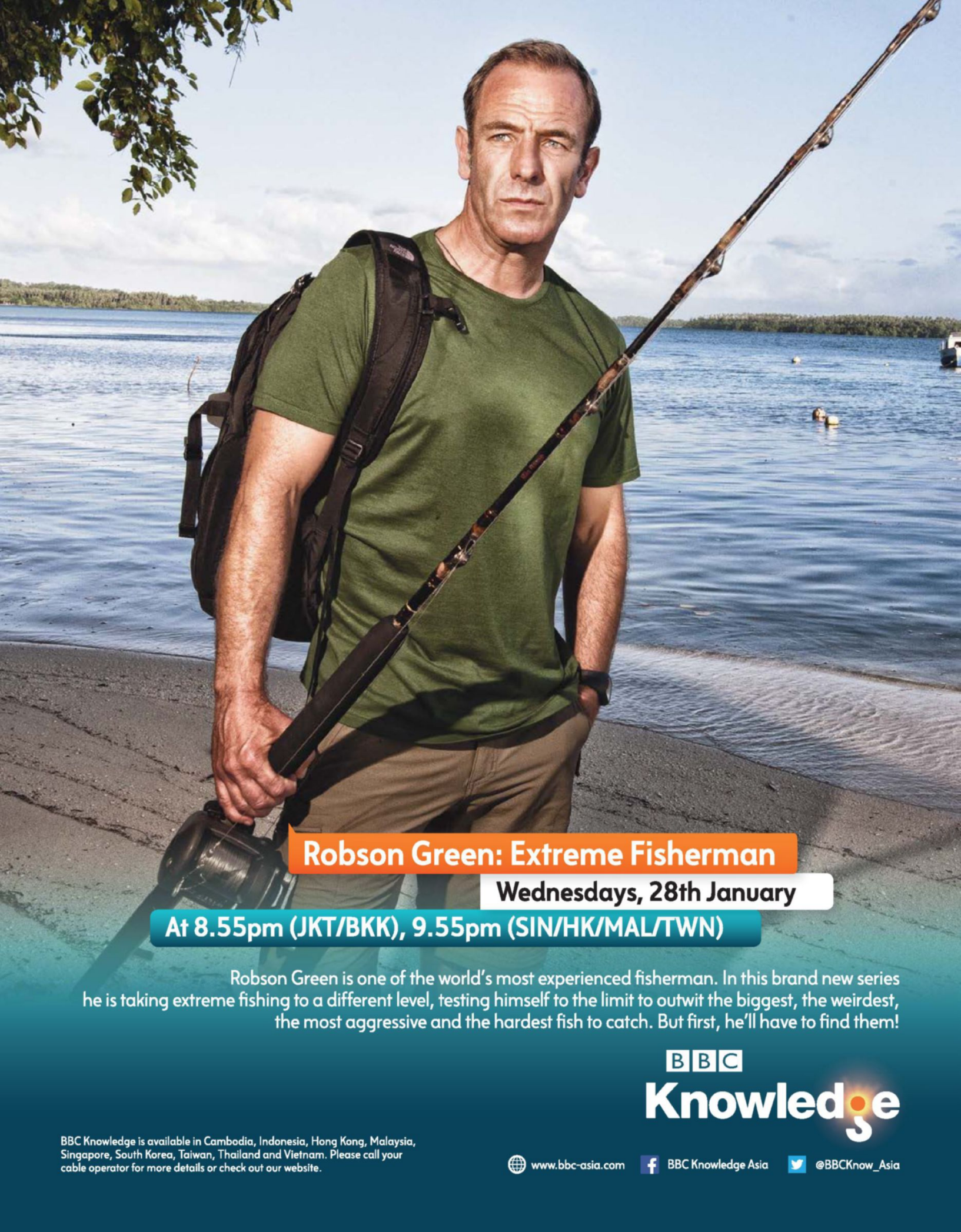
The effectiveness of homeopathy, the reality of climate change, whether hot water freezes faster than cold… there's a whole host of seemingly random issues capable of causing even the most rational of people to descend into fury. But why these? There's no outrage, for example, over the 1,000-plus deaths caused each year by the radioactive gas radon seeping into UK homes. No-one's much bothered about whether, say, teapots benefit from being warmed first.

There is, however, one red mist issue I dearly wish someone would sort out: how aircraft stay up in the air. Over a century after the Wright Brothers, this one still provokes furious argument. Some say it's simply the result of the wing deflecting the oncoming air downward. Others insist it's the result of the bulging upper surface of the wing forcing the air to move faster over the top than below. Both have their failings – and both can trigger the red mist effect.

I'm currently working with the Institute of Physics to find a really satisfactory explanation that will please everyone. One idea is to hold a competition, like the one back in the 1990s to find the best explanation for what the Higgs particle is all about. But there's just one problem: who'll decide which explanation of flight is the right one?

ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham

ILLUSTRATOR: ROBERT G. FRESSON



Robson Green: Extreme Fisherman

Wednesdays, 28th January

At 8.55pm (JKT/BKK), 9.55pm (SIN/HK/MAL/TWN)

Robson Green is one of the world's most experienced fisherman. In this brand new series he is taking extreme fishing to a different level, testing himself to the limit to outwit the biggest, the weirdest, the most aggressive and the hardest fish to catch. But first, he'll have to find them!

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Highlights

TV Channel

Kangaroo Dundee

Premieres 15th January. Thursdays at 8.55pm (JKT/BKK), 9.55pm (SIN/HK/MAL/TWN)

Join tough Australian, Chris Barns, as he and his team rescue orphan joeys, nursing them back to life so they can be released back into the wild. *Kangaroo Dundee* offers a rare insight into the bizarre biology and fascinating family life of one of the Earth's most charismatic and unusual animals.

Dangerous Roads Series 3

Starts 9th January. Fridays at 5.25pm (JKT/BKK), 6.25pm (SIN/HK/MAL/TWN)

Six British celebrities travel along some of the most extraordinary highways on the planet, taking in the breathtaking landscapes and the fascinating characters who live, work and travel these routes on a regular basis.

Ben and James versus the Arabian Desert

Starts 14th January. Wednesdays at 9.50pm (JKT/BKK), 10.50pm (SIN/HK/MAL/TWN)

Adventurer Ben Fogle and former British Olympian James Cracknell have travelled across some of the most inhospitable places on Earth. Now, they are embarking on their greatest challenge yet - to be the first Westerners to cross the Empty Quarter of the Arabian Desert alone and unguided.

Wild Shepherdess

Premieres 22nd January. Thursdays at 9.50pm (JKT/BKK), 10.50pm (SIN/HK/MAL/TWN)

At a time when traditional farming is under threat, Kate Humble experiences some of the oldest and most extreme animal husbandry on the planet to learn the skills that have fed and clothed us for centuries.

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